CS 1: Introduction To Computer Programming, Fall 2013

Assignment 3: File Under "Fractal"

Due: *Thursday, October 31, 02:00:00*

Coverage

This assignment covers the material up to lecture 9.

Part What to hand in

You will be handing in two files for this assignment.

You should collect the answers to sections B and C into a file called `lab3a.py`. For the questions in section C, you should write your answers in comments, but write the corrected code outside of comments. Functions in section C will not be tested (but they will, of course, be graded!).

For section D, you should hand in the file `lab3b.py` containing your code for the miniproject. You shouldn't hand in any of the files that your code generates, or any of the drawings either. We can generate these ourselves. Similarly, don't hand in the drawing program `lab3bdraw.py` we provide for you!

Both files should be handed in to csman as usual.

There are a number of supporting files you need to download. They include test scripts for both `lab3a.py` and `lab3b.py`, called (naturally enough) `lab3a_tests.py` and `lab3b_tests.py`, the template file for `lab3b.py` (described in detail below), the text of two Shakespeare plays (Hamlet and Macbeth) that you'll use for testing with `lab3a_tests.py`, and the drawing program `lab3draw.py` you'll use with the miniproject. To make this easy on you, we've collected all of these supporting files into a zip file called lab3.zip. You should download this onto your computer and unzip it to get the files you need; ask a TA if you have any problems with this.

NOTE: Just because a test script works does not guarantee that your code is perfect; the test script may not be comprehensive. You should *always* test your code by hand (interactively in the Python shell) to make sure it does what you expect. Test scripts are very helpful, but they are not a crutch.

Part A: Installing new Python packages

There are no new Python packages to install this week.

Part B: Exercises

As usual, put docstrings in all of your functions.

1. [**15**] Write a function called `list_reverse` which takes as input a list and returns the reverse of the list without changing the original list. The function should use the `reverse` method of lists in the function body. *Hint:* list slices might come in handy.

   Examples:

```
>>> list_reverse([21, 33, 42, 67, 99])
[99, 67, 42, 33, 21]
>>> list_reverse([])
[]
>>> list_reverse([1])
[1]
>>> lst = [1, 2, 3, 4, 5]
>>> list_reverse(lst)
[5, 4, 3, 2, 1]
>>> lst
[1, 2, 3, 4, 5]   # no change to original list "lst"
```

2. [**20**] Write a function called `list_reverse2` which takes as input a list and returns the reverse of the list without changing the original list. The function should use the `range` function and a `for` loop (but not the `reverse` method of lists). *Hint:* Consider using the three-argument form of `range` — what should the begin point, end point, and step size be?

   Examples: same as in the previous exercise.

3. [**20**] Write a function called `file_info` that takes a single input (a string representing the name of a text file), and returns the number of lines, the number of words, and the number of characters in the file as a tuple with three components (line count, word count, character count). Lines are defined to be sequences of characters ending in a newline character, as we saw in the lectures. You can use the `split` method on strings to identify the number of words in a line. Don't worry about punctuation; "words" here just means a sequence of characters separated by spaces. The character count should include the newline characters at the end of each line. Don't forget to close the file before your code returns. You may assume that the file exists, so that opening it will not cause an error. You may use the `readline` function in this exercise but do not use the `readlines` function, because this may cause excessive memory use if the file is very large.

   Hint: Use counter variables to store the current values of the three items you're computing.

   This function actually does the same thing as the Linux `wc` program, which stands for "**w**ord **c**ount".

   Examples:

```
# Assume that the file 'text.txt' exists and has 1009 lines, 18050 words
# and 102418 characters.
>>> file_info('text.txt')
(1009, 18050, 102418)
```

4. [**10**] Write a variant of the last function called `file_info2` which takes the same input (a filename) and outputs a dictionary containing the line count, word count, and character count using the keys `'lines'`, `'words'`, and `'characters'` respectively. The body of this function should call the `file_info` function you just wrote above, capture the results by unpacking the tuple, package them into a dictionary with the appropriate keys, and return that dictionary.

   Examples:

```
# Same example as above.
>>> file_info('text.txt')
(1009, 18050, 102418)
>>> file_info2('text.txt')
{'lines': 1009, 'characters': 102418, 'words': 18050}
```

5. [**20**] Write a function called `longest_line` which takes as input the name of a text file and returns the length of the longest line of the file, as well as the line itself (a (length, line) tuple is returned from the function). Again, make sure your function closes the file before it returns from the function, and don't use the `readlines` function. If more than one line has the longest length, return the (length, line) corresponding to the first such line. You may assume that the file has at least one line. You should count the newline character at the end of the line as part of the line.

   Hint: The pattern of using an `if` statement inside a `for` loop comes in handy here.

   Example:

```
# Assume that the file 'lines.txt' exists and is at least one line long.
>>> longest_line('lines.txt')
(181, 'This is a really, really, really, really, really, really, really, really, really, really, really, really, really, really, really, really, really, really, almost absurdly long line.\n')
```

6. [**10**] Write a function called `sort_words` which takes in one argument (a string), uses the `split` method on strings to separate it into a list of words (removing all space characters in the process), sorts the list of strings (using the `sort` method on lists), and returns the sorted list of words. Before you begin, type in:

```
>>> help(''.split)
>>> help([].sort)
```

to learn more about the `split` method on strings and the `sort` method on lists. (Also, you should experiment with them in WingIDE.) The `sort` method compares strings by their dictionary order, so `'apple'` comes before `'banana'`.

Don't worry about punctuation characters in the string; in other words, you can assume that the `split` method splits correctly on word boundaries.

Examples:

```
>>> sort_words('')
[]
>>> sort_words('foo bar baz')
['bar', 'baz', 'foo']
```

7. [**15**] Convert the binary number 11011010 to decimal. Show how you did it. **Note:** Typing `0b11011010` into the Python interpreter will give you the answer, but this is not what we mean by "showing how you did it"!. What is the largest eight-digit binary number in decimal? Write the answers in Python comments.

Part C: Pitfall: Poor coding style

In this section we'll look at what's called *coding style*. There are many ways to write code which works correctly but which are hard to read and understand by others. Beginning programmers, who haven't usually had the experience of reading or modifying a lot of code written by other programmers, tend to have a hard time understanding this. The thing to remember is that even if you're the only one who will ever use your code, you will inevitably want to add new features to it at some point, and then you will have to be able to read the code that you yourself wrote six months, or a year, or five years before. If you can't do that easily, your productivity will suffer because you'll have to waste a lot of time relearning what you meant when you wrote the code originally.

Compared to most programming languages, Python tends to make it easy to write readable code, and over the years of Python's existence, a body of knowledge has accumulated about the best ways to write readable code. Some of the guidelines we use have been written up in the CS 1 Python style guide (posted on the course Moodle page). In this section, we will show you some examples of badly written code and ask you to fix it.

1. [**30**] Go and read the Python style guide on the CS1 website. Skip over those sections that deal with features of Python we haven't discussed yet in class. **Note:** there is nothing to hand in for this exercise.
2. What are the style errors for the following snippets of Python code? Write down what the style error(s) is/are (in comments) and write a corrected version (not in comments). You can ignore style errors relating to docstrings (missing or present). You can also ignore style errors relating to the content of comments (*i.e.* whether what they say is relevant or meaningful) but not on their grammar or formatting.

    1. [**15**] This example has three different kinds of style mistakes.

    ```
    def sc(a,b,c):
        return a*a*a+b*b*b+c*c*c
    ```

    2. [**20**] This example has four different kinds of style mistakes.

    ```
    def sumofcubes(argumenta, argumentb, argumentc, argumentd):
        #reutrn sumof cubes of argsa b c &d
        return argumenta * argumenta * argumenta + argumentb * argumentb * argumentb + argumentc * argumentc * argumentc + argumentd * argumentd * argumentd
    ```

    3. [**10**] This example has two different kinds of style mistakes. They are somewhat less severe than the style mistakes seen so far, but they are style mistakes nonetheless.

    ```
    # 2 different kinds of style mistakes:
    def sum_of_squares(x, y):
           return x * x + y * y
    def sum_of_three_cubes(x, y, z):
       return x * x * x + y * y * y + z * z * z
    ```

Part D: Miniproject: L-Systems

In this week's miniproject, we'll be exploring a fascinating topic called *L-systems*. An L-system is a string rewriting system (we'll explain what this means below) that can also be used to generate very complex images. L-systems were invented by the biologist Aristid Lindenmayer as a way of modeling the processes involved in plant development. L-systems can also be used to generate self-similar ("fractal") images, which is what we'll be doing here.

This will also be our first encounter with computer graphics in the course. Fortunately, you won't have to write the code that does the actual drawing; it will be provided for you. Instead, you will be writing the code that generates drawing instructions and saves them to a file. This allows us to concentrate on the interesting parts and leave the gory details of graphics for later (don't worry, we *will* cover those details later!).

Before we describe the project itself in detail, we have to cover some background material. **Do not skip this! You absolutely need to know this before writing the code for the project.** If you do skip right to the problem description, we can almost guarantee that you will waste way more time than you save. Also, as Douglas Adams would advise, **don't panic!** Just because the description below is long doesn't mean that the code you need to write is long. In fact, there are only six functions to write, and none of them needs to be longer than about 20 lines.

Background: Turtle graphics

Images will be drawn on the screen for this project using a system called *turtle graphics*. This was originally used in the Logo programming language in the 1960s and has been ported to many other programming languages, including Python. A good reference for turtle graphics is the Wikipedia page, and the Python `turtle` module is documented here. (Note that the documentation refers to a graphics system called `Tk`. We will learn all about `Tk` later on in the course, but you don't need to know anything about it now. Also note that Python supports a number of graphics systems that don't require or use turtle graphics; it's only one of many ways to do graphics.)

The basic idea of turtle graphics is to have a window on your computer screen which is a "canvas" which can be drawn on, and a "turtle" which is a moving "pen" that can draw lines on the canvas. The "pen" can be up or down; if it's up it doesn't draw when it moves, and if it's down it does. The pen has a location, given in (x, y) coordinates; this location starts at (0, 0), which is in the exact center of the drawing window. The pen also has an orientation, specified in degrees from the horizontal. An orientation of zero degrees means that the pen draws horizontally to the right, an orientation of 90 degrees means that the pen draws vertically upwards, and so on. The position and orientation of the pen can be changed by commands. So to draw a square box 10 units on a side, you could issue these commands:

```
# Assume that the pen is down.
forward(10)
right(90)
forward(10)
right(90)
forward(10)
right(90)
forward(10)
right(90)
```

You could substitute `left` for `right` in the code above, and it would also work. You can also go to a particular location on the screen (in terms of its `x` and `y` coordinates) using the `goto` function. That's basically all you need to know about turtle graphics for this project. In fact, the actual Python code that uses the `turtle` module has been provided for you (see below), so you won't have to write Python code that has all kinds of `forward`, `left` and `right` commands. (We want you to understand how it works, though.)

Background: L-systems

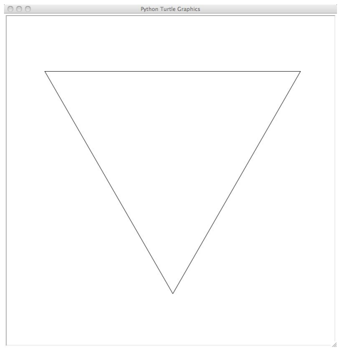
An L-system ("L" stands for "Lindenmayer") is a way of describing a structure (typically an image) using strings. You start with an *axiom*, which is the starting string, and a set of rules for converting strings into new strings. The way this conversion works is that some of the letters in a string have corresponding rules that say what they should be replaced by. To find the next version of a string, take each letter of the string, and if it's the left-hand side of any rule, replace it with the right-hand side of the rule; otherwise, simply copy it to the new string. You can repeat this process to generate yet another string, and keep going or stop at any point. We'll assume that a particular character can only occur as the left-hand side of at most one rule.

In addition to generating new strings, the characters in a string can be interpreted as simple drawing commands. Successively-generated strings will typically generate ever more complex drawings. The drawings are what we're really interested in creating.

An example is worth a thousand words, so here's an example. We're going to draw what is called a *Koch snowflake*. This will be one of the drawings you'll be making as part of the project, so pay attention! :-)

The Koch Snowflake

The Koch snowflake will be represented as an L-system by strings containing three characters: "F", "+", and "-". Each of these characters is a simple turtle graphics drawing instruction: "F" means to go forward one unit (the size of the unit is not important), "+" means to turn the turtle 60 degrees to the right, and "-" means to turn the turtle 60 degrees to the left. The axiom (initial string) is "F++F++F". If you think about it, what this does is to draw an equilateral triangle one unit on a side: "forward one unit, right 60 degrees, right another 60 degrees, forward one unit, right 60 degrees, right 60 degrees, forward one unit" and the turtle ends where it began. If you drew it out, it would look like this:

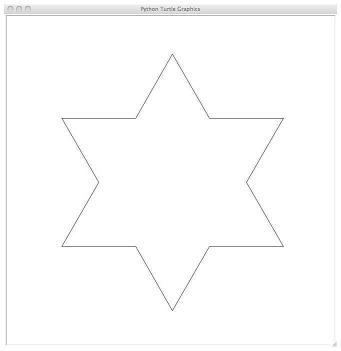


This is a pretty simple image, but the essence of L-systems is that they contain rules for transforming simple images into more complex ones. Furthermore, these rules work at the string level, not directly at the image level. You specify these rules by specifying a particular character and what it gets transformed into. There is only one rule for the Koch snowflake, and it is this: the character "F" gets transformed into the string "F-F++F-F". Any other character in the string (for example, "+" or "-") is just copied into the new string. So let's see how the original string would get transformed:

```
starting string: "F++F++F"
rule: "F" --> "F-F++F-F"
next string: "F-F++F-F" + "+" + "+" + "F-F++F-F" + "+" + "+" + "F-F++F-F"
          --> "F-F++F-F++F-F++F-F++F-F++F-F"
```

Notice that the "+" characters in the starting string go unchanged into the next string, whereas each "F" character gets converted into the string "F-F++F-F" and then everything is concatenated together to give the next string.

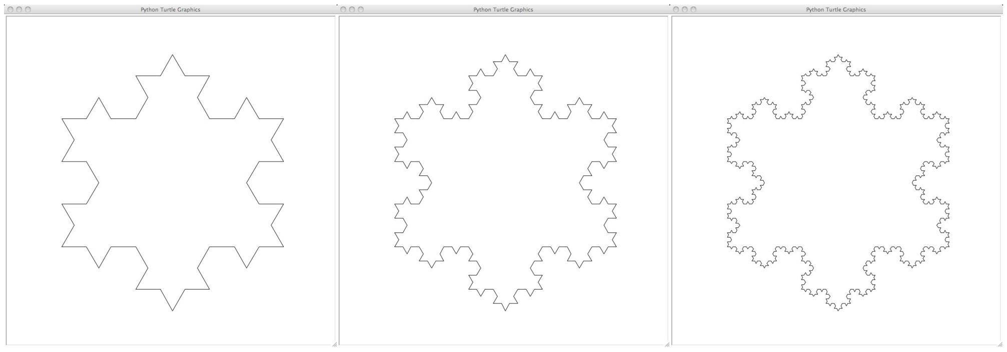
If we use the new string to generate an image like we did for the starting string, we get the following picture (scaled to fit in the same size window):



Notice that each edge of the original triangle has been replaced by four lines. Graphically, the change is like this:

```
                  /\
________  --> ___/  \___
```

After doing this, we can repeat this process over and over to get new images. Each new image is "bumpier" than the one that preceded it. Here are a few more images in this sequence, all resulting from the application of the exact same rules:



Note also that some L-systems (though not the Koch snowflake) include characters that have no drawing action associated with them. These serve as "scaffolding" for the construction of the strings which do include characters with graphics actions associated with them.

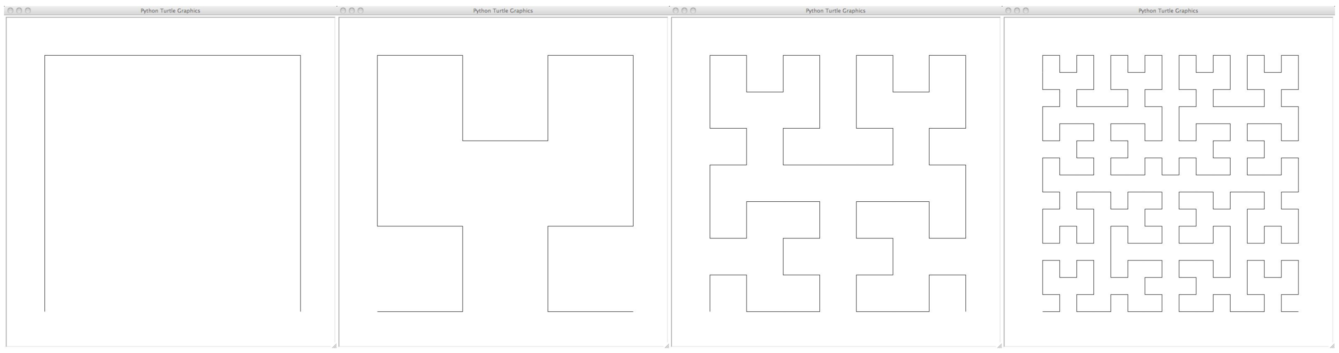
It's very important that you understand everything so far. If not, ask a TA for help.

Some sample images

Before getting into a description of the code you have to write, let's take a look at some of the images you'll be generating. The description of each image will include a level number which represents how many times the rules were applied to the starting string to get the image; level 0 means the image corresponds to the starting string, level 1 means that the rules were applied once, level 2 means twice, and so on.

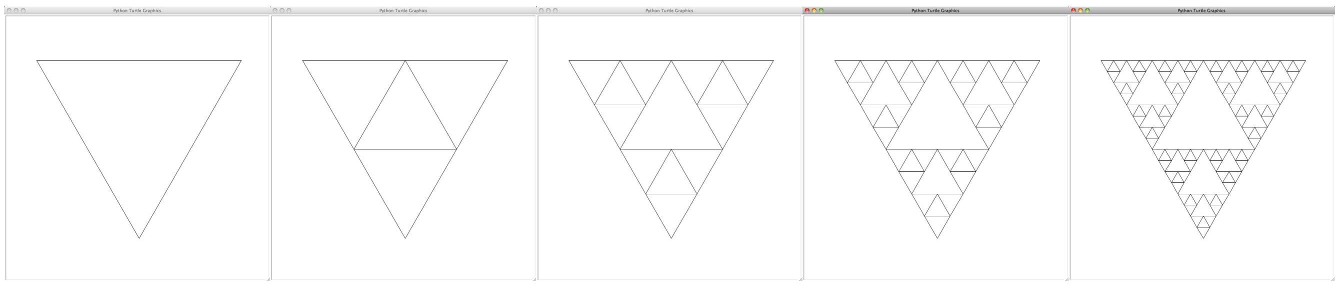
The Hilbert curve

The Hilbert curve is an interesting set of drawings using right angles only. Here are levels 1, 2, 3 and 4:



The Sierpinski triangle

The Sierpinski triangle is an interesting set of drawings using triangles. These images are *fractals* in that the component triangles are similar to the image as a whole. The Koch snowflake and Hilbert curve are also fractals, but it's less obvious. Here are levels 0 to 4:



OK, enough preamble; let's get to the code you have to write!

Template code and data representation

To give you a head start, we're supplying you with a skeleton version of the miniproject code called `lab3b.py` which is part of the zip file of supporting files mentioned at the beginning of the assignment. Fill it in with working implementations of the functions. Do this by (a) writing a docstring (replacing the text `<docstring>` in the function) and (b) replacing the line that says `pass` with your code. None of the functions needs to be more than about 20 lines long (not counting docstrings), and some can be less than 10 lines long. One advantage of using the template code is that there are data structures defined for you in the code that you will need.

Once you've filled in your definitions, running the `main()` function will generate a series of drawing files for each of the L-systems in the program (Koch snowflake, Hilbert curve, and Sierpinski triangle).

Let's talk a bit about how the L-systems are represented in the template code. Each L-system is represented by two different Python dictionaries. One contains the starting string and the rules for the L-system, and the other describes how characters in the L-system string are translated into drawing commands.

Here's an example for the Koch snowflake:

```
koch = { 'start' : 'F++F++F',
         'F'     : 'F-F++F-F' }

koch_draw = { 'F' : 'F 1',
              '+' : 'R 60',
              '-' : 'L 60' }
```

In the first dictionary, the key `'start'` is associated with the starting string for that L-system (as `koch['start']`). Then, for each kind of character in the string that has a rule associated with it, there is a corresponding key/value pair in the same dictionary. Here, there is only one rule, corresponding to the character `'F'`, so that rule says to convert each `'F'` character into the string `'F-F++F-F'` (which is `koch['F']`). Of course, Python strings are immutable so you can't just change them, but you can create new strings where instead of the original `'F'` character you put in `'F-F++F-F'`.

The dictionary `koch_draw` says how to interpret a string in terms of drawing instructions. There are three types of drawing instructions, each consisting of a letter followed by a positive integer:

1. instructions like `'F 1'`, which means to go forward one unit in the direction the turtle is currently heading.
2. instructions like `'L 60'`, which means to rotate the turtle to the left by 60 degrees. The angle can be any integer between 0 and 360.
3. instructions like `'R 60'`, which is like `'L 60'` except that you rotate the turtle to the right.

You'll see how these dictionaries are used in the problems below.

Functions you have to write

You have to write six functions to complete the project.

1. [**30**] Write a function called `update` which takes two arguments:
    1. a dictionary, which specifies both the starting string and the update rules for a particular L-system (like the `koch` dictionary described above)
    2. an L-system string

    It will generate the next version of the L-system string by applying the L-system rules to each character of the string and combining all the strings into one big string. Any character which is not a key in the L-system dictionary should be copied into the new string unchanged.

    Examples:

    ```
    >>> koch = { 'start' : 'F++F++F', 'F' : 'F-F++F-F' }
    >>> k0 = koch['start']  # starting string
    >>> k0
    'F++F++F'
    >>> k1 = update(koch, k0)
    >>> k1
    'F-F++F-F++F-F++F-F++F-F++F-F'
    # same as:
    # 'F-F++F-F' + '+' + '+' + 'F-F++F-F' + '+' + '+' + 'F-F++F-F'
    >>> k2 = update(koch, k1)
    >>> k2
    'F-F++F-F-F-F++F-F++F-F++F-F-F-F++F-F++F-F++F-F-F-F++F-F++F-F++F-F-F-F++F-F++F-F++F-F-F-F++F-F++F-F++F-F-F-F++F-F'
    ```

You see that applying the rules to the starting string repeatedly makes the string for this L-system grow pretty quickly!

This function is very short (less than 10 lines). Use the `in` operator to test if a character is a key in the L-system dictionary.

2. [**10**] Write a function called `iterate` which takes two arguments:

    1. an L-system dictionary as described in the previous problem.

    2. an integer `n` which should be 0 or greater.

    It returns the string which results from starting with the starting string for that L-system and updating `n` times.

    Examples:

    ```
    >>> koch = { 'start' : 'F++F++F', 'F' : 'F-F++F-F' }
    >>> iterate(koch, 0)   # return starting string
    'F++F++F'
    >>> iterate(koch, 1)   # apply 'F' rule once
    'F-F++F-F++F-F++F-F++F-F++F-F'
    # same as:
    # 'F-F++F-F' + '+' + '+' + 'F-F++F-F' + '+' + '+' + 'F-F++F-F'
    >>> iterate(koch, 2)
    'F-F++F-F-F-F++F-F++F-F++F-F-F-F++F-F++F-F++F-F-F-F++F-F++F-F++F-F-F-F++F-F++F-F++F-F-F-F++F-F++F-F++F-F-F-F++F-F'
    ```

    Hints: This function is very easy to write (about 5 lines long) if you use the `update` function you just defined to do the string updating. Basically, you just have to start with the right string and use a loop.

3. [**15**] Write a function called `lsystemToDrawingCommands` which takes two arguments:

    1. a dictionary whose keys are characters in L-system strings and whose values are drawing commands (like `koch_draw` above)

    2. an L-system string

    It returns the list of drawing commands needed to draw the figure corresponding to the L-system string.

    Examples:

    ```
    >>> koch = { 'start' : 'F++F++F', 'F' : 'F-F++F-F' }
    >>> koch_draw = {'F' : 'F 1', '+' : 'R 60', '-' : 'L 60' }
    >>> k0 = koch['start']
    >>> lsystemToDrawingCommands(koch_draw, k0)
    ['F 1', 'R 60', 'R 60', 'F 1', 'R 60', 'R 60', 'F 1']
    >>> k1 = iterate(koch, 1)
    >>> lsystemToDrawingCommands(koch_draw, k1)
    ['F 1', 'L 60', 'F 1', 'R 60', 'R 60', 'F 1', 'L 60', 'F 1', 'R 60', 'R 60', 'F 1', 'L 60', 'F 1', 'R 60', 'R 60', 'F 1', 'L 60', 'F 1', 'R 60', 'R 60', 'F 1', 'L 60', 'F 1', 'R 60', 'R 60', 'F 1', 'L 60', 'F 1']
    ```

    Note that there is no requirement that every character in an L-system string must correspond to a drawing instruction. For instance, the Hilbert curve L-system generates strings with characters that don't need to be drawn; they are just there to make the rules work properly. Those characters can be ignored when generating drawing instructions. Basically, you check to see if a character is in the drawing dictionary, and if it isn't, you ignore it. Otherwise, you add the corresponding drawing command to the list.

    This function is very short.

4. [**45**] Write a function called `nextLocation` which takes three arguments:

    1. the current `x` coordinate value of the turtle
    2. the current `y` coordinate value of the turtle
    3. the current direction (angle from the horizontal) the turtle is facing
    4. a drawing command, like `'F 1'` or `'L 60'`

    It generates the next location and direction of the turtle after that drawing command has executed. It returns a tuple of three values, the next `x` coordinate of the turtle, the next `y` coordinate, and the next angle. Note that the `x` and `y` values should be floating-point numbers even if the commands contain integers; that's because (say) going one unit at a 45 degree angle moves you only about 0.7071 each in the `x` and `y` directions. You can still use integers for the angle, but make sure that it lies between 0 and 360 degrees (the `%` operator will help here).

    This is the only tricky function in the miniproject. You need to do a bit of trigonometry to calculate the new values. You need to know that Python uses radians, not degrees, as arguments to the trig functions `sin` and `cos` (which live in the `math` module, of course). To convert an angle in degrees to an angle in radians, use this formula:

    ```
    (angle in radians) = (angle in degrees) * (pi / 180)
    ```

    `pi` also lives in the `math` module.

    Hints: Use the `split` method on strings to extract the parts of a command (*i.e.* the letter `'F'`, `'R'` or `'L'` and the integer value). Note that left rotations add to the angle and right rotations subtract from it. Forward motions require that you compute the `x` and `y` changes using standard trig formulas and the current angle. Your TA will help you if you're a bit shaky on the trigonometry.

    Examples:

    ```
    >>> nextLocation(0.0, 0.0, 0, 'F 1')
    (1.0, 0.0, 0)
    >>> nextLocation(0.0, 0.0, 0, 'L 60')
    (0.0, 0.0, 60)
    >>> nextLocation(0.0, 0.0, 0, 'R 60')
    (0.0, 0.0, 300)
    >>> nextLocation(1.0, 2.0, 60, 'F 1')
    (1.5, 2.8660254037844384, 60)
    ```

5. [**30**] Write a function called `bounds` which takes one argument: a list of commands such as those generated by `lsystemToDrawingCommands`. It computes the bounding coordinates of the resulting drawing, which means the minimum and maximum `x` and `y` coordinates ever achieved by the turtle as it moves to make the drawing. The function returns a tuple of the `(xmin, xmax, ymin, ymax)` coordinates, where each coordinate is a float (not an int).

    Examples:

    ```
    >>> bounds(['F 1'])
    (0.0, 1.0, 0.0, 0.0)
    >>> bounds(['R 90', 'F 1'])
    (-1.8369701987210297e-16, 0.0, -1.0, 0.0)
    >>> bounds(['L 90', 'F 1'])
    (0.0, 6.123233995736766e-17, 0.0, 1.0)
    >>> bounds(['R 45', 'F 1'])
    (0.0, 0.7071067811865475, -0.7071067811865477, 0.0)
    ```

    Note that some of the numbers are just `0.0` with tiny roundoff errors; your code doesn't have to give the exact same numbers, but they should be close (say, within 0.0001 of the values above). Of course, the input lists for real drawings would probably be a lot longer.

    This may seem to be a difficult function to write, but if you've written the `nextLocation` function correctly, it's very easy! You start the `x` and `y` minimum/maximum values off at zero, and then for each command in the list call `nextLocation` with the current `x`, `y` and angle values and the command. Use the return values to update the current `x` and `y` coordinates and angle, and use that to update the minimum and maximum `x` and `y` values. Once you're through the list, you'll have the overall minimum and maximum `x` and `y` values, which you can put into a tuple and return.

    The reason we need these bounding values at all is so that when we draw the figure corresponding to the list of drawing commands, we can use the bounding values to scale and center the figure so that it looks good. You won't have to do that because it's taken care of in the drawing program you'll use to draw the figures (described below).

6. [**15**] Write a function called `saveDrawing` which takes three arguments:

    1. a filename to write to

    2. the bounds of the resulting drawing, as a tuple of floating-point numbers `(xmin, xmax, ymin, ymax)` (presumably generated from the `bounds` function described above).

    3. a list of drawing commands (presumably generated from the `lsystemToDrawingCommands` function described above).

This function will write this information to the file corresponding to the given filename by first writing the bounds information on a single line (as four floating-point numbers with spaces between them but no parentheses or commas), and then by writing the drawing commands to the file, one per line. Use the `write` method on file objects to write lines to the file. (We haven't talked about this method in class, but it just writes a string to a file.) Note that you have to supply the newline character yourself when you use `write` (it doesn't automatically supply one for you). Note also that the drawing commands are already in the form of strings, so writing them to a file is easy. Don't forget to close the file you open!

Given a bounds tuple of `(0.000000, 9.000000, -7.794230, 2.598080)` and a commands list of `['F 1', 'L 60', 'F 1', 'R 60', ...]`, the output file's contents would look like this:

```
0.000000 9.000000 -7.794230 2.598080
F 1
L 60
F 1
R 60
... (etc.)
```

This function is very short.

The drawing program

The program you should use to display your finished graphics files is called `lab3draw.py` and is part of the zip file of supporting files mentioned previously. Assuming that you have a file of drawing commands called `mydrawing`, you can draw it in one of two ways:

```
% python lab3draw.py mydrawing
```

or:

```
% python lab3draw.py -fast mydrawing
```

The `%` represents the terminal prompt (yours may be different). You should run this program directly from the terminal, not from inside `WingIDE`. Make sure that you run it when in the same directory as the drawings you want to display.

The difference between the two ways of running the program shown above is that the first way will draw the drawing one line at a time, and you can watch it as it draws. The second way draws the entire drawing before it displays anything. The second way is greatly superior for drawings that have a large number of lines, since it will take dramatically less time. The first way is more interesting to watch :-)

Another useful feature of the `lab3draw.py` program is that you can use it to draw multiple drawings, where each drawing's commands comes from a different file. You do this by specifying the name of each file to draw on the command line, like this:

```
% python lab3draw.py mydrawing1 mydrawing2 ...
```

or like this:

```
% python -fast lab3draw.py mydrawing1 mydrawing2 ...
```

(if you want the drawings to be drawn as quickly as possible). This will cause each drawing to be displayed in turn; you simply hit the `<return>` key to move from one drawing to the next (the program will prompt you to do this). This can be very convenient when you want to inspect a whole group of drawings.

Testing

We've provided a test suite in a program called `lab3b_tests.py` with the supporting files. Run these tests to check your code. We don't guarantee that they will catch all bugs, but if your code passes the tests it's a lot more likely that it's correct than if it doesn't! Before running the tests, try running the drawing program described above on your files of drawing commands; if the drawings look reasonable, run the tests. If not, you can still run the tests to help pinpoint the problem(s).

References

- The Wikipedia entry on L-systems is a good reference on the topic.
- This site allows you to interactively experiment with L-systems in your browser, and it's fun!