CCPS 109 Computer Science I

(**outline version by Ilkka Kokkarinen, April 20, 2020**)

Outline

This course is an introduction to computer science and programming in Python 3 programming language. Its topics are broken down into eleven separate modules:

1. Python as a scriptable calculator
2. Functions that make decisions
3. Sequence types string, list and tuple
4. Sequence iteration
5. General repetition
6. Educational example programs
7. Lazy sequences
8. Recursion
9. String processing
10. Numerical computation with numpy
11. Classes and objects

Materials

The public GitHub repository `ikokkari/PythonExamples` always contains the latest versions of lecture notes (as PDF files) and all example programs (as Python scripts) of this course.

The software needed in this course is free to download and use in both Windows and Apple computers. Students can either (1) download and install the Anaconda package manager and use its Spyder environment to write, run and test their programs on their local computers, or (2) create a free account on the free repl.it cloud-based programming environment, and import the course repositories into their "repls" to work on.

Weekly labs

The first four modules of this course use the problems offered in the free CodingBat Python environment to drill in the basics of the core language. The simple yet excellent and educational problems on that site allow beginning students to quickly pinpoint what their functions are doing right and wrong, and what issues still remain to fix. When combined with another excellent online utility of Python Tutor that allows these functions to be animated and stepped through forwards and backwards, the educational power at least doubles.

After acquiring proficiency with the language with these two free training sites so that the students can start applying this knowledge in solving problems with the language as their ally instead of the opponent, the lab problems from fifth week onwards have been chosen from the problem collection "109 Python Problems for CCPS 109". The public GitHub repository `ikokkari/PythonProblems` always contains the latest versions of the automated tester script and necessary data files to solve these labs.

Grading

In addition to the labs done weekly for the "109 Python Problems for CCPS 109" collection, students can freely choose and implement any number of additional labs from the same collection. All these labs are submitted all at the same time at the end of the course as a single Python program `labs109.py` that should contain all functions that the student has successfully completed so that they pass the automated tester script.

The course grade given at the end of the course is computed with the following formula. To earn the passing grade of 50% (D minus), the student must successfully complete ten labs. After that, every additional lab that they complete adds one more point to their course grade. Therefore to get the highest possible course grade of 90% (A plus), the student has to complete fifty lab problems out of the 109+ problems offered.

Module 1: Python as a scriptable calculator

Introduction

Python 3 is a modern programming language whose core syntax is simple enough to learn in five weeks, and yet behind this simple syntax lies an entire universe of tremendous power. This module shows you how to set up this system to start your exploration of programming and computer science by first using Python as a scriptable calculator that can operate on not just numbers, but on characters and text.

Topics

1. Launching the Python interactive environment either locally or on the cloud.
2. Entering arithmetic expressions inside the Python REPL.
3. Defining names that are associated with values, and using these names inside later expressions.
4. Basic operations of integer arithmetic, with a suggestion to avoid floating point numbers in your work if possible.
5. Importing new functions from the standard library modules and using them in your computations.

6. Representing text as string literals in Python.
7. Composing complex text strings from simpler pieces with the f-string mechanism.

Learning objectives

After this module, students can launch the Python interactive environment either on their local computer (Anaconda/Spyder) or on the cloud (repl.it). They know how to evaluate arbitrary arithmetic expressions in the REPL window, and how integer arithmetic operators work in Python. They can create names that remember values that were assigned to them, and use these names in later expressions to refer to results that were calculated earlier. They can open, edit, save and execute scripts in some Python IDE, and can make these scripts print results for the user to see. They can define text literals as ordinary and f-strings in Python. They can import new functions and data types from the standard library into their scripts, and know where to go in the official Python documentation to learn how to use these functions in their code.

Readings

1. "Python Lecture Notes", sections "1.1. Expressions", "1.2. Scripts", "1.3. Naming things", "1.4. Assignment operator", "1.5. Types", "1.6 Importing functionality from modules", "1.7. Some useful standard library modules".
2. GitHub repository `ikokkari/PythonExamples`: `first.py`
3. YouTube playlist "CCPS 109 Computer Science I, Python" videos: "Python 1-1: Overview", "Python 1-2: And God created integers", "Python 1-3: Give me a name instead of a number", "Python 1-4: Executable text".

Activities

The purpose of this first module is to get acquainted with the Python Interactive Development Environment (IDE) in which the Python programs are created and executed. Instead of the old-school installation straight from the source at www.python.org, students who choose to work locally on their own computers can download and install the **Anaconda** package manager, and do their work inside the **Spyder** IDE there. Alternatively, students may choose to work on a cloud-based Python environment `repl.it` that can be accessed anywhere via a web browser. All examples, exercises and lab problems in this course can quite well be completed in either environment.

Option 1 (**Anaconda/Spyder locally**): Download and install Anaconda Individual Edition. While this behemoth is installing, you might as well use that waiting time to download the entire repositories ikokkari/PythonExamples and ikokkari/PythonProblems as zip archives (use the green Clone/Download button), and unzip these archives into folders `PythonExamples` and `PythonProblems` into whatever place in your file system you normally store your data files. Start up Anaconda, and from there start Spyder. (In the first run, both of these might be a bit sluggish to start up, but they will get there.) Use File->Open... to open the script `first.py` into an editor window. Press the green play button to execute the script whose editor window is currently active. Observe the results in the console window. When this script asks you to enter your name and age, give it something so that the script can proceed.

Option 2 (**repl.it on the cloud**): Create yourself a free account on the site repl.it under which your files will be stored under. Click the black "**import repo**" button on the top right corner, enter the URL "[`https://github.com/ikokkari/PythonExamples`](https://github.com/ikokkari/PythonExamples)" into the dialog box and click "**Import from GitHub**". You should now see a Python 3 "repl" named `PythonExamples` under your account that contains all the example programs from this course. Do the same for the URL "[`https://github.com/ikokkari/PythonProblems`](https://github.com/ikokkari/PythonProblems)" to import the automated testing environment for the lab problems for this course. Go to the `PythonExamples` repl and press the green "Run" button to execute the script `first.py`. When the script asks you to enter your name and age, give it something so that the script can proceed. To make the "Run" button execute some other script, you have to edit the second line of the file `.replit` to read `run="python3 scriptname.py"` where you should replace `scriptname` with the actual name of the script that you want to run.

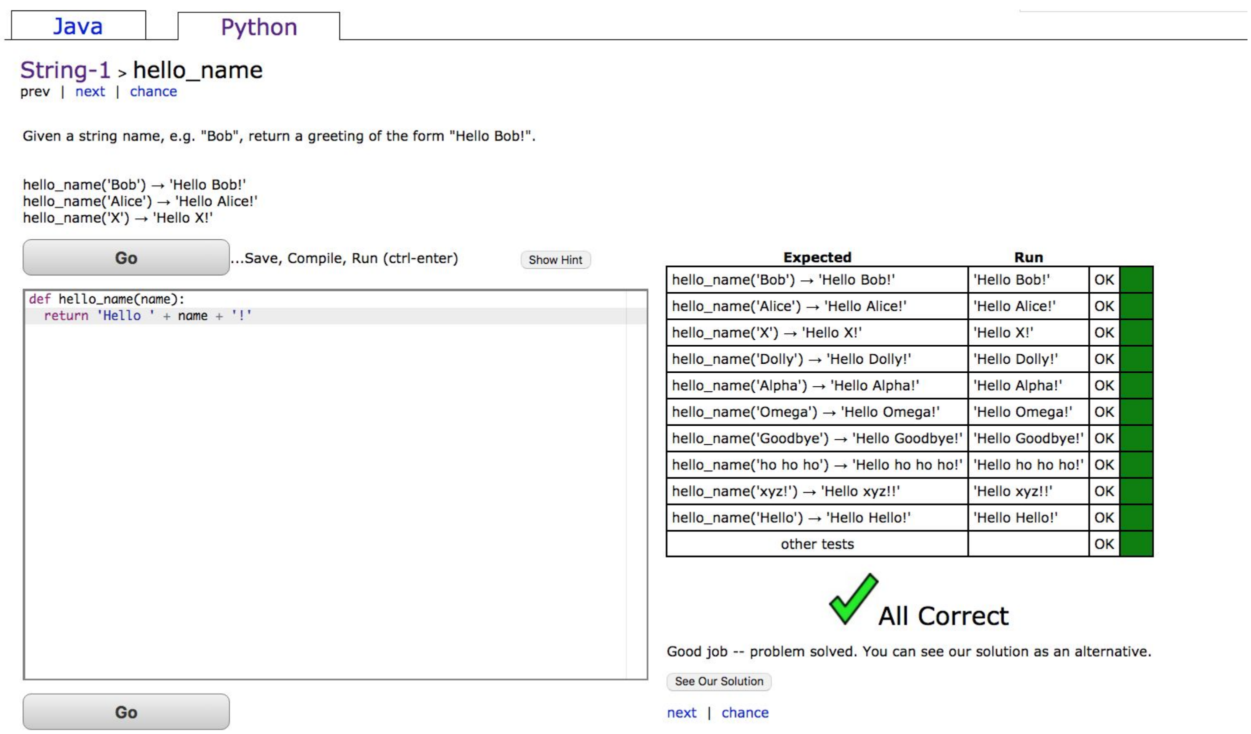
Lab problems

During the first five modules, this course uses the excellent CodingBat Python interactive training site. This site contains lots of small programming problems whose purpose is to drill in the core Python language that we learn during the first five weeks. From the sixth week onwards, we move on to apply this knowledge to solve problems from the collection "109 Python Problems for CCPS 109".

Every CodingBat problem is solved as a script that defines exactly one function. Since we will be writing functions next week onwards, this week is devoted to setting up the programming environment (either Spyder or repl.it) and learning to use the CodingBat interactive coding environment. Create yourself a free account at CodingBat so that it will remember your solved problems and the solutions that are works in progress. Then, in the collection "String-1", go to the problem `hello_name`. The editor pane already contains the signature of the function that you should always keep exactly as it was given, since otherwise the automated testers. Under the function signature, type one line of text (please don't just copy-paste from here)

```
 return 'Hello' + name + '!'
```

indented two spaces to denote that this statement is inside the function `hello_name` that is being defined in this script. Once you have done this, press the "Go" for CodingBat to grade your function by giving it a bunch of test cases and verifying that your function returns the correct result for each. You should see something resembling the screenshot below:



Next to your editor pane, CodingBat shows a table with all the test cases in the "Expected" column, with the individual results from your function in the "Run" column. The green box means that your function returned what it was supposed to return for the test case in that row. If your function had returned anything other than the expected result, that row would then have a red box at the end to show you the existence of a bug in your code. (Don't worry, you will write your first bug soon enough to see plenty of red!)

One caveat of using CodingBat of this writing is that it uses Python 2 internally, so the Python 3 nice things that we learn in this course do not work in these scripts. For example, trying to implement `hello_name` using an f-string will only result in a syntax error.

Module 2: Functions that make decisions

Introduction

The simple two-way decision is the foundation of all computation from which all other computational operations are built from bottom up, all the way down to the logic gates of the computer processor up to the highest levels of abstraction inside Python. The existence of forks in the road that the execution of a program has to choose from makes it possible for the outcome to be different for different inputs given to that program, instead of every computation leading to Rome regardless of these inputs.

Topics

1. Defining your own functions that compute and return a result that depends on the function arguments.
2. Purpose of whitespace to indicate nesting of statements inside a Python script.
3. Two-way decisions to branch the execution of a script into two mutually exclusive branches based on the truth value of some condition.
4. Equality and order comparisons in Python.
5. Building up larger decision trees from two-way decisions via nesting and laddering.
6. Expressing more complex conditions with logical connectives.

Learning objectives

After this module, students are able to first define functions in their scripts, and then call these functions properly later in the code using different argument values. They understand the difference between the function printing the result versus returning it. They can explain the connection of the whitespace indentation that starts a Python statement and the nesting of that statement inside the Python script. They can make their functions perform simple two-way if-else statements, and combine these two-way decisions into more complex decision trees by nesting them and creating if-else ladders. They recognize the logical connectives `and`, `or` and `not`, and explain how the truth value of a condition built with these depends on the truth values of its subconditions.

Readings

1. "Python Lecture Notes", sections "2.1. Defining your own functions", "2.2. Simple two-way decisions", "2.3. Outcomes of equality", "2.4. Complex conditions", "2.5. If-else ladders".
2. GitHub repository ikokkari/PythonExamples: `conditions.py` `timedemo.py`
3. YouTube playlist "CCPS 109 Computer Science I, Python" videos: "Python 2-1: Verb every word to me", "Python 2-2: Forks on the road", "Python 2-3: The Galton board of reality", "Python 2-4: A Skinner box for humans, localized entirely within your computer", "Python 2-5: Once in a century".

Activities

Study the example script `timedemo` as an example of how to do computations with calendar dates and times with the `datetime` module in the standard library. Use this knowledge to adapt the script to find out what day in the future you will be exactly twice as old as you are today. (Compute how many days you have been alive so far, and then add that many days to the current date.) Then, find out which day of the week you were born in.

Lab problems

Since the humble two-way decision is the fundamental building block of all computations, having this operation at our disposal allows us, in principle if not always in practice, to solve any computational problem as a Python function... provided that the problem has an upper limit to how large its input can be, so that we can encode all possibilities into a decision tree implicitly executed by the statements of the function. This is especially the case when the arguments given to the function are truth values so that each argument is either `True` or `False`, with no third alternative.

The problems in the CodingBat Python sections Warmup-1, Logic-1 and Logic-2 will have you write functions that cover all possible situations of their argument values with a small handful of decisions properly nested and laddered. **Your task this week is to solve at least ten problems of your choice from these three sections**. This ought to drill the Python syntax (including that annoying redundant colon after every condition, and that == and = are different things, as are also `//` and `/`) into your fingertips, while at the same time your mind gets accustomed to the task of breaking down a complex decision into a decision tree made of simple two-way decisions.

When comparing your solutions to those of other students, remember that whenever you come up with one way to organize a decision tree, there always would have been many other result-equivalent ways to do so.

Module 3: Sequence types string, list and tuple

Introduction

There are only so many interesting questions that we can ask about a single integer or other scalar value. However, in the current era of terabytes, even everyday computers that us commoners, not just the five richest kings of Europe, can afford to own, can effortlessly process sequences that consist of millions, even billions, of such scalar values of data. Sequences allow our Python programs aggregate scalar values together under a single name, and the powerful polymorphic functions and operators on sequences can handle all types of sequences in a uniform fashion.

Topics

1. Embedding special characters inside string literals with escape sequences.
2. The slicing operator for Python sequences, as demonstrated by slicing pieces from existing text strings.

3. Strings as immutable sequences of Unicode characters.
4. The structurally flexible and heterogeneous lists in Python.
5. Constructing new list objects from existing sequences with list comprehensions.

Learning objectives

After this module, students know how to make up text string literals that can contain arbitrary Unicode characters. They can slice and dice text strings forwards and backwards with the slicing operator `[]` of Python. Their ability to represent data has expanded from scalar values into sequences of arbitrary values as Python lists. Students can take an existing list and transform it into a new list with list comprehensions.

Readings

1. "Python Lecture Notes", sections "3.1. String literals from Unicode characters", "3.2. String literals from arbitrary pieces", "3.3. String slicing", "3.4. Lists made of things" and "3.5. List comprehensions". (Students looking for extra material can also study the section "3.6. Nested list comprehensions", but this topic is not needed in this course.)
2. GitHub repository ikokkari/PythonExamples: `listdemo.py` `stringdemo.py` `comprehensions.py` `tuples.py`
3. YouTube playlist "CCPS 109 Computer Science I, Python" videos: "Python 3-1: It slices, it dices, and so much more!", "Python 3-2: Pretty objects all in a row", "Python 3-3: All sequences eager and lazy", "Python 3-4: Definition of terse"

Activities

When a function that is more complex than a couple of lines does not return the answers you expect, it is often convenient to be able to step through the execution to see exactly what is going on in each step. We shall see how to use a debugger inside Spyder or repl.it, but before that, go to the excellent Python Tutor site and copy-paste one of the functions that you have written earlier into the editor pane on that page, followed by a line in which you call that function for some argument values. To see a step-by-step animation of the function execution, press the button "Visualize execution" to take you to the screen where you can step through your execution forward and backward, and see exactly the values associated with each name at each step during this execution.

Lab problems

To practice handling sequences of data and learn to understand how these sequences can be freely sliced into smaller pieces and concatenated into larger pieces, CodingBat sections Warmup-2, String-1 and List-1 contain a host of excellent problems ready to be solved with the Python language learned in this week's module. Your task, same as last week, again is to drill in the language syntax into your fingertips while your mind adapts to think about entire sequences of data of unlimited length instead of mere individual scalar values. Therefore, **this week you should again complete at least ten, but preferably more, problems chosen from these three sections.**

Module 4: Sequence iteration

Introduction

In computing, we are accustomed to the idea that duplication of bytes by the billions is essentially free. The same principle also applies inside the computer program. Once you have discovered a way to solve some problem for one element, you can place this solution inside some repetition control structure that then solves it for the entire sequence of such elements. This module introduces the basic for-loop control structure to do this very thing.

Many problems can be expressed in, or at least converted to the form of some small local operation being repeatedly performed for the elements of some cleverly chosen existing sequence. Especially when asked to do something five times, the computer program does the exact same thing as a human who keeps a running count going "one, two, three, four, five", thereby unknowingly iterating through a simple arithmetic progression that turns out to be isomorphic to the actual problem that exists outside the mind of that human. That, and the computer program usually starts counting up from zero because that turns out to be mathematically convenient. However, a computer can count up to a billion much faster than us humans, even though just like us, it does not need to remember all the numbers that it has previously processed, but only the number that it is currently at.

Module topics

1. Iterating through the elements of an arbitrary sequence with the same for-loop.
2. Lazy sequences that produce their elements one at the time on command.
3. The extremely memory-efficient `range` sequences for the commonly needed arithmetic progressions of integers.
4. Files as sequences of lines, each line a sequence of characters.
5. Tuples as compact immutable sequences of a handful of elements.
6. Sets and dictionaries that are used to remember the things that the function has seen and done.

Module learning objectives

After this module, students can write for-loops to iterate through the elements of the given sequence, and have the body of the for-loop perform the same computation for each element. This computation can involve updating the local state of the function such as tallying up the sum or the maximum of the elements seen so far. They know how to represent arithmetic progressions as `range` objects, and understand why such a `range` requires far less memory to store compared to an eager `list` that contains its elements explicitly. They know the difference between mutable lists and immutable tuples, and which operations are possible based on that. Students can create a fresh new `set` and use it to store the values encountered during the function execution, and can explain why asking a set whether it currently contains some element is much faster than asking the same question from a list.

Readings

1. "Python Lecture Notes", sections "4.1. Processing items individually with for-loops", "4.2. Iterator objects", "4.3. Integer sequences as range objects", "4.4. Files as sequences", "4.5. Tuples as immutable sequences", "4.7. Members only", "4.8. From keys to values". (Students looking for extra reading can also check out sections "4.6. Breaking tuples into components" and "4.9. Assorted list, set and dictionary goodies", but these topics are not required in this course.)
2. GitHub repository ikokkari/PythonExamples: `defdemo.py` `setsanddicts.py` `wordcount.py`
3. YouTube playlist "CCPS 109 Computer Science I, Python" videos: "Python 4.1: For your elements only", "Python 4-2: Memory of a goldfish", "Python 4-3: Frank Benford, gumshoe who works scale", "Python 4-4: Those who can't remember the past...", "Python 4-5: Memories of lit"

Lab problems

The ability to make your function perform the same operation for every element of an arbitrary sequence turns out to be quite a lot more powerful than it might initially eem. In fact, we now have enough Python language backing us up that in principle, we could already express literally any computation that can be realized within the confines of our physical universe! (The previous sentence should be understood in the same sense as the sentence "Once you learn all the letters of the alphabet and the punctuation and other characters that can appear inside a manuscript, you can write any book whatsoever", which is true only in a very special theoretical sense, but not in any practical sense.)

After such an energetic start, we can confidently face the problems in the CodingBat Python sections String-2 and List-2. These problems require the use of some for-loop to process the elements of the given string or a list. However, note that at least at the time of this writing, many of these problems have obviously been copy-pasted from the older and larger CodingBat Java site in that they talk about "arrays", which Python does not have. For the purposes of every such question, whenever you see the word "array", simply mentally substitute the word "list" in its place.

Module 5: General repetition

Introduction

In many computational problems we have a straight and narrow road ahead of us, and the goal that we are trying to achieve is promised to be somewhere along that road. Often, we know how far we have to go the moment the moment we start the first step, as in iterating through sequences that have a known beginning and a known end. However, in general it is not possible to know how many steps we need to execute until the goal state is reached.

Instead of having to decide in the beginning how many times we are going to repeat the body of the loop, a while-loop breaks this potentially infinite journey into local two-way decisions of the form "Are we there yet?" While we have not reached the goal state, we execute the body of the while-loop once more. If the goal is somewhere along the execution path, this mechanism will eventually get us there. It is also important to realize that sometimes we are already standing on the goal to begin with, and taking even a step away from it would give the whole game away. Furthermore, you must keep going so that each step takes you forward somehow so that you are not just marching forever in place. Even so, there exist problems where the goal simply does not exist anywhere in the program execution path, thus making that journey to be doomed to go on forever in an infinite loop.

Topics

1. Using a while-loop to repeat the body of statements until the desired goal is reached.
2. Finite and infinite loops.
3. The optional else-block after a Python loop.
4. Binary search to narrow down even an astronomical number of possibilities to just one.
5. Breaking out of the execution of a loop, or just skipping directly to the next round.

Module learning objectives

After this module, students know the syntax and use of the general repetition structure of a while-loop in Python for situations where it is not known in the beginning how many times the loop body should be executed to achieve the goal of the problem. They know that an infinite loop is an actual possibility, just like doing nothing is another possibility that we don't often think about in real world systems biased towards action. They recognize the optional else-block after a Python loop and its behaviour in functions written by other people. They know the binary search algorithm when applied to searching inside a sorted random access sequence, and can use the implementation in the Python standard library. They know the effect of the `break` and `continue` statements inside the loop and can use them in their own functions, but with the knowledge that doing so is never necessary and is in fact impure in the structured programming spirit.

Readings

1. "Python Lecture Notes", sections "5.1. Unlimited repetition", "5.2. While not there yet, take one more step towards it", "5.3. Binary search", "5.4. The power of repeated halving", "5.5. Nested loops".
2. GitHub repository `ikokkari/PythonExamples`: `mathproblems.py` `cardproblems.py` `hangman.py`
3. YouTube playlist "CCPS 109 Computer Science I, Python" videos: "Python 5-1: Are we there yet?", "Python 5-2: Straight and narrow road", "Python 5-3: A handful of symbolism", "Python 5-4: Cold as the cards lie", "Python 5-5: A crooked little pair"

Activities

With all the language in our fingertips that we need to solve computational problems, the time has come to thank CodingBat for its service. This week, we move on to the graded labs of this course in the repository `ikokkari/PythonProblems` that we last saw during the first week of this course, either in Spyder or `repl.it` depending on your choice of working environment, and see how the actual labs of this course are executed and tested.

Run the automated tester script `tester109.py` to execute the tests for all the functions currently implemented in the `labs109.py` file. To ensure that the tester script is working, this file already contains a working implementation `ryerson_letter_grade` of the first problem "Ryerson Letter Grade" from the collection "109 Python Problems for CCPS 109". The tester should finish quickly and you should see the outcome in the REPL window. (Numbers for the running time of the tester and how many problems are possible can be slightly different.)

```
ryerson_letter_grade: Success in 0.001 seconds.
1 out of 1 functions (of 125 possible) work.
```

Every lab problem that you solve in this course consists of exactly one function. This function must have the exact signature required in the problem specification and be written in the file `labs109.py` for the automated tester script to be able to find it. Even if you work on these functions in some files, you need to copy the function to `labs109.py` to be able to test it.

Edit the function `ryerson_letter_grade` to return `"Fail"` instead of `"F"`, and run the tester again. You should now receive a message of the test failing with a checksum mismatch. This means that your function returned the wrong answer for at least one of the test cases that the automated tester gives to this function. Restore the function to its original form and watch it pass the test again.

In this course, there are no partial marks given for effort for functions that do not pass the tester script cleanly and promptly. For each of the functions to be tested, the automated tester script generates a large number of pseudorandom test cases (this term means that these test cases may seem random, but will always be the same for everyone every time these tests are run), gives them one by one to your function, and computes a "checksum", sort of a digital signature, of the answers returned by your function.

If this checksum is different from the checksum originally generated from the answers returned by the instructor's model solution, that means that these functions must have returned a different answer to at least one test case. However, **the checksum mismatch reveals only the existence of at least one such difference**, but cannot pinpoint which test case it was, and whether these functions disagreed on the answer for just one or a thousand test cases.

The specification of each function in the problem collection comes with a handful of representative test cases to try out the function with. Once the function passes these test cases, you know that at least you have solved the correct problem. However, **your function returning the expected result for the given test cases does not mean that the function being correct for the infinite number of possible untried test cases**, of which the automated tester throws a shotgun blast at your function.

Lab problems

Having gained the understanding of how the automated tester works and what its various messages mean for the functions being tested, we can start working with the graded labs. The first three lab problems from the collection "109 Python Problems for CCPS 109" chosen for us to sharpen our teeth with this week are:

1. Ascending list (`is_ascending`)
2. Cyclops numbers (`is_cyclops`)
3. Suppressed digit sum (`suppressed_digit_sum`)

Module 6: Some educational example scripts

Introduction

The material of this week's module does not introduce any new major language features, since the existing ones are already ample enough for all the problems we wish to solve. Instead, we go through a number of example programs that showcase the language structures used so far, and most importantly, how to put these structures together in different ways to create different behaviour and outcomes. Python already comes with a module for importing data from JSON files and turning their contents into Python objects so that we can perform some poor man's data science on them.

With no new language to learn this week, the reading material instead contains three sections on software testing and how to come up with good test cases for the functions that you write both during this course and the rest of your career afterwards. All interesting functions contain bugs while they are being developed. The faster we can pinpoint the existence of these bugs so that the logic of the function can be reorganized to work correctly, the better.

Topics

1. Reading in data encoded in the JSON standard format for representing structured data, and processing it with Python.
2. Writing functions to solve problems in a problem domain of playing cards and some familiar games that are played with them.
3. The `global` keyword that allows your function to talk about data in the same module.
4. Having a while-loop run around a large problem space looking for a goal that satisfies our expectations for the given problem.
5. Using custom sorting criteria with the optional `key` function given to `sort` function.

Learning objectives

This module reviews and reinforces the core control structures that Python functions are made of, and how these structures can be put together in various combinations to solve interesting computational problems. This knowledge is necessary for advancing from the knowledge level of the Bloom taxonomy to the level of applying this knowledge to solve problems. Students know how to import data from JSON files to give our programs something interesting from the real world to deal with instead of just always doing everything with made-up numbers. They know the mechanism to make their functions remember things by naming these things outside the function in the same module so that they continue to exist even between calls. They can modify the standard `sort` function to use a custom sorting criteria by giving it the optional `key` function, and create such `key` functions as one-liners with `lambda` expressions.

Readings

1. "Python Lecture Notes", sections "6.1. Different levels of programming errors", "6.2. Software testing", "6.3. Designing good test cases", "6.4. JSON".
2. GitHub repository `ikokkari/PythonExamples`: `stringproblems.py` `countries.py` `mountains.py` `specialnumbers.py`
3. YouTube playlist "CCPS 109 Computer Science I, Python" videos: "6-1: Some hazards we know", "6-2: Loop and a half men", "6-3: Powerful words", "6-4: On the primal side".

Lab problems

This week, another three graded labs were chosen from the collection "109 Python Problems for CCPS 109" to function as our training ground and a confidence course:

1. Three summers ago (`three_summers`)
2. Nearest smaller element (`nearest_smaller`)
3. What do you hear, what do you say? (`count_and_say`)

Module 7: Lazy sequences

Introduction

So far, our functions have been dealing with random-access sequences so that even though we usually process such sequences linearly from beginning to end, our functions could jump to any position in the sequence to access the data there in the same constant time. However, such eager sequences are fundamentally restricted by the amount of memory available to Python. Especially many combinatorial sequences such as "all the possible ways to choose nine cards out of the deck of 52 cards" could not possibly fit in the memory.

Lazy sequences work much better in situations of this nature. As far as the rest of the Python language knows, lazy sequences are sequences that can be processed linearly from beginning to end with the same ordinary for-loop that we previously used to process the elements of eager strings and lists. However, instead of all the elements of the sequence existing simultaneously in memory, lazy sequences generate these elements one at the time as requested using computational means to do so. Such sequences therefore have no inherent limit for their length, and could even be infinitely long. Decorators that transform lazy sequences into different lazy sequences can then extract from this infinity the finite part that they need.

Topics

1. The fundamental difference between lazy and eager sequences, and the advantages and downsides of each representation.
2. Defining lazy sequences easily with generator functions that `yield` their results one at the time.
3. Generator decorators that can be applied to transform an existing sequence into some different lazy sequence.
4. The highly useful generator decorators of the Python `itertools` module.

Learning objectives

After this module, students can explain the difference between eager and lazy sequences, and what type of situations each kind of sequence is appropriate. They know how to turn their ordinary functions to print out values into generators that `yield` these same values one at the time for further processing. Since these generators are functions that take arbitrary arguments, even other generators, students then automatically know how to write generators that decorate an existing sequence given to it as an argument. They are aware of the Python `itertools` module and can explain its general purpose, and can consult the documentation to use the decorators `islice` and `takewhile` to turn an infinite lazy sequence into a finite one. They know how to consult the same documentation to use the combinatorial generators in the standard library `itertools` module to loop through all possible pairs, triple, subsets, permutations and other basic combinations of an existing sequence such as a deck of playing cards.

Readings

1. "Python Lecture Notes", section "7.1. Generators".
2. GitHub repository `ikokkari/PythonExamples`: `generators.py` `reservoir.py` `hamming.py`
3. YouTube playlist "CCPS 109 Computer Science I, Python" videos: "7-1: To get all I deserve and to give all I can", "7-2: Let George do it", "7-3: Zero knowledge"

Lab problems

The three lab problems chosen for this week from the collection "109 Python Problems for CCPS 109" continue the theme of dealing with sequences with more complicated operations that have to combine ideas from previous lectures.

1. Revorse the vewels (`reverse_vowels`)
2. Once I zig, you gotta zag (`create_zigzag`)
3. Bulgarian solitaire (`bulgarian_solitaire`)

Module 8: Recursion

Introduction

Recursion, the act of function calling itself for smaller argument values as part of its own execution, has the reputation of being the most mysterious and esoteric technique learned in a first programming course. It also has a reputation of being useless, but this follows from the fact that most introductory programming courses only ever teach simple linear recursions with the cliches factorial example, leaving the students with an impression that recursion is just a needlessly convoluted and mathematical way to do the job of a for-loop.

The power and usefulness of recursion lie in its ability to branch into several directions and combine the results of the recursive calls into the answer returned from the current level. After the factorial example used to teach the concept of self-similarity of a problem that makes it suitable for recursion, the examples of this module involve problems that greatly benefit from recursive branching in solving them in a manner clearly superior to the traditional imperative approach.

Topics

1. Self-similarity of computational problems as the key to unlock the recursive implementation to solve that problem.
2. Downsides of recursion compared to solving that same problem with loops.
3. Recursions that branch into two or more directions to solve the original problem.
4. Branching recursion to explore an exponential space of solutions.
5. Decorating functions with functions in Python.
6. Recursions that take exponential time due to needlessly solving the same subproblems, and how such wild recursions are tamed with memoization using `@lru_cache`.

Learning objectives

After this module, students recognize and can explain what makes a particular function recursive, and why such recursive functions are the natural choice for solving computational problems that exhibit self-similarity. They know why deep linear recursions are no good in practice, and know the rule that every such linear recursion should have been written as iteration to begin with. They can recognize a branching recursion that suffers under the exponential burden of needlessly repeated subproblems, and can decorate their recursion with `lru_cache` to make the function remember the subproblems that it has solved so far, so that the next time around their results can be simply looked up instead of fully recomputed all the way down from scratch. They have seen enough examples of branching recursions for interesting computational problems to appreciate the qualitative difference between recursion and iteration in practical use.

Readings

1. "Python Lecture Notes", sections "8.1. Recursive functions for self-similar problems", "8.2. Practical application of recursion", "8.3. Downsides of recursion", "8.4. Applying functions to other functions", and "8.5. Defining small functions as lambdas". (Advanced students looking for additional knowledge outside the course can also check out the sections "8.6. Dynamic evaluation of text as code" and "8.7. Functional programming tools".)

2. GitHub repository `ikokkari/PythonExamples`: `recursion.py` `functional.py`
3. YouTube playlist "CCPS 109 Computer Science I, Python" videos: "Python 8-1: A self of selves", "Python 8-2: Remember to remember", "Python 8-3: If you can't beat them, join them", "Python 8-4: Until time itself runs out", "Python 8-5: Twisty little passages", "Python 8-6: Paint every corner"

Lab problems

Recursion is not a separate language feature on its own in Python or any other programming language, but merely a different way of using and putting together the existing features of that programming language. Any lab problem from "109 Python Problems for CCPS 109" and elsewhere that you have solved and will be solving with loops could have also been solved with recursion instead, at least in theory if not always in practice. However, unless genuine branching into multiple directions is involved, there is little point in using recursion to do the work of a simple loop and then just make your function crash with a stack overflow error once the recursion gets deep enough, except as practice to get accustomed to recursion and its use in general.

Some problems in the 109 lab problems collection that benefit from the use of recursion are the following. There are also several more, although all of them have been all placed in the second half of the collection.

1. Lattice paths (`lattice_paths`)
2. Split within perimeter limit (`perimeter_limit_split`)
3. Sum of distinct cubes (`sum_of_distinct_cubes`)

You should definitely use the `lru_cache` decorator in the first two problems, but it will not help you in the third one.

Module 9: String processing

Introduction

Even though everything inside a computer is made of mere small numbers under various disguises, programs that deal with the real world and especially its human aspects have to deal with textual data. In this course, the wordlist `words_sorted.txt` serves tons of interesting textual data for our Python functions to derive interesting results from. When combined with recursion and lazy sequences from the previous two modules, computation of complex questions about recreational linguistics becomes a breeze.

Topics

1. Applying the ability to slice and dice string objects and put these pieces together into words from a very large list of words, to find all the words that have some curious property from recreational linguistics.
2. Using binary search to speed up the search for words that start or end with the given prefix.
3. Using simple regular expressions to look for patterns inside words.
4. Using recursion to generate all possible strings that match the given rule.
5. Combining recursion and lazy sequences to systematically visit all possible solutions to the given recursive problem, instead of returning merely the first or the best such solution.

Learning objectives

After all the multitude of examples from this module, students are confident in their abilities to operate on character sequences. They can explain why binary search is a good algorithm to use when they know the data to be sorted. They know that regular expressions exist as a universal text pattern matching mechanism and which Python module contains functions to harness this power. They can use the branching possibilities of recursion to extend the existing string prefix into all possible continuations within the given constraints.

Readings

1. There are no lecture notes for this week. Instead, this week we go straight to the source, so to speak, and learn to study the Python standard library documentation. After that, our example classes showcase the power of Python string operations, especially when combined with recursion and lazy sequences.
2. GitHub repository `ikokkari/PythonExamples`: `wordproblems.py` `morse.py` `wordfill.py`
3. YouTube playlist "CCPS 109 Computer Science I, Python" videos: "Python 9-1: Trie as you may", "Python 9-2: A multitude of words", "Python 9-3: Steamy computations", "Python 9-4: It means what I choose it to mean".

Activities

Read through the documentation page "Text Sequence Type - str" to find out what kinds of handy things the ordinary Python strings can do for you. There is no point memorizing any of the standard library documentation, but you should get a general overview of the things that are available there so that you don't end up needlessly reinventing these wheels all the time. After all, for some function to gain the exclusive membership in the standard library, it must have a general and useful nature in doing something that is not specific to any particular problem domain. Functions become part of the standard library to scratch very real itches that every programmer has constantly. Chances are that you have already had those same itches several times, as can often be seen by googling an answer from Stack Overflow and watching how quickly Google auto-completes the search, but perhaps having been unaware of the existence of the scratchers that have existed for decades.

Lab problems

In the spirit of the topic of this week's module, the lab problems from "[109 Python Problems for CCPS 109]()" for this week deal with text strings and collections of strings.

1. Detab (`detab`)
2. Expand positive integer intervals (`expand_positive_intervals`)
3. Possible words in Hangman (`possible_words`)

Module 10: Numerical computation with numpy

Introduction

The numpy extension, already included in both the Anaconda package manager and repl.it cloud-based programming environment, can be used to perform big and heavy numerical calculations that would require excessive time or space if done with bare Python. The flexibility of data in Python requires its internal data representation to need more space than the storage of that information would technically require. However, for many data sets coming from the real world, the numerical nature of this data is known and certain. This knowledge may allow more efficient and compact internal representations as numpy arrays that pack these homogeneous data items together like sardines, mercilessly cutting off all the parts that don't fit inside the uniform Procrustean bed that is assigned for each individual data element.

These low-level operations performed close to hardware are still fully integrated as native citizens of Python language. The numpy array data type can represent not such vectors but matrices and tensors of arbitrary number of dimensions, and mathematical functions for numerical operations do the right thing even when applied to operands of incompatible dimensions. Even better, the scipy library for numerical analysis and all the domain-specific libraries such as scikits-learn built on top of it allow amateurs and scientists alike to trust the correctness of their numerical analysis.

Topics

1. Using the `sys` module for introspection to find out things about the current state of computation.

2. The idea of flexible representations of data whose exact nature we cannot predict, versus inflexible but more compact representations for data of known fixed nature.
3. Creation and manipulation of low-level numpy arrays of arbitrary dimensions of uniform elements of data.
4. Mathematical operations on numpy arrays.
5. Image processing with numpy, with the acceptance of such images as actually being matrices of small numbers under all that colourful presentation.

Learning objectives

This one module by itself does not turn anyone into a data scientist, but the educational value is understanding the qualitative difference in the contrasting approaches of core Python and numpy to the issue of what data even is and how it is represented inside programs. However, after this module the students can read through simple numpy examples without any fancy operations involved in them and explain, often after quickly consulting the numpy documentation that they now know to keep open in another browser tab, what each statement does and why it is there. Aided with the documentation, they can create numpy arrays and perform basic mathematical calculations on them at whichever level they are in their mathematical knowledge outside this course. They can appreciate the power of numpy in its ability to perform image processing, and that a pixel image is just a matrix of numbers that encode the colours.

Readings

1. "Python Lecture Notes", sections "10.1. The numpy array data type", "10.2. Operations over numpy arrays", "10.3. Processing pixel images as numpy arrays".
2. GitHub repository `ikokkari/PythonExamples`: `sysandos.py` `numpydemo.py` `imagedemo.py` (students who catch the numpy fever from this module can check out more advanced examples `fractals.py` `matplotdemo.py` `scipywords.py` that showcase the capabilities on numpy, scipy and matplotlib)
3. YouTube playlist "CCPS 109 Computer Science I, Python" videos: "Python 10-1: The cost of everything", "Python 10-2: Bytes laid bare", "Python 10-3: Pie pants, one size fits all".

Activities

Of all the functions that you have written so far or seen as examples in the course material that receive a list of integers as their argument, rewrite some of these functions of your choice to receive and handle numpy arrays as parameters instead. As you perform this conversion for various functions, especially those that create and return another list built with a repeated application of `append`, pay attention to how drastically the internal logic and structure of that function can change when it is forced to deal with fixed-size arrays for data representation, the way that all programming was done (and still is) in lower-level programming languages such as C++ and Java.

Lab problems

Since the collection "[109 Python Problems for CCPS 109]" was designed so that each problem could be solved with only the core Python language and recursion for those problems that gain from it, it contains no problems that would make the function deal with numpy arrays and their operations. Instead, the following three problems have been chosen for their instructive and educational value, and have at least some numerical flair in them in that they could be used as examples in the previous activity.

1. Hitting integer powers (`hitting_integer_powers`)
2. Calling all units, B-and-E in progress (`is_perfect_power`)
3. Reverse every ascending sublist (`reverse_ascending`)

Module 11: Classes and objects in Python

Introduction

When our problems are simple enough, low-level representations of data laid bare are sufficient to deal with them. However, for a data type intended to represent some important problem-domain concept such as an ordinary playing card would be useful to exist as a code as an abstraction on its own, rather than our code having to deal with the low-level representation as "a tuple of a suit and a rank that you must handle with string operations". Once the concept of a playing card exists as a data type on its own, the user code can perform its operations on that concept at higher level, and does not have to hardcode and implement the internal representations of playing cards as a tuple of strings.

Even though this fact lies hidden below the surface of the deceptively simple syntax, Python is very much of an object-oriented programming language, more so than most programmers with experience from other classic mainstream languages such as Java or C++ would assume. This last module shows how to define your own high-level data types as classes, of which any number of individual instances can be created. The methods defined inside the class allow the implementations of the operations on that data type to be hidden inside the type, instead of the functions operating on the data type on the outside aware of its internal representation details. The operators of Python language can be made to work with our classes merely by defining certain standardized "magic methods" inside the class that the Python compiler will then translate the language operators into.

Topics

1. Thinking in higher-level abstractions about concepts, instead of their low-level representations inside our language.
2. Defining classes in Python. Methods and data inside classes and objects.
3. Constructors and other magic methods that turn the class into a truly naturalized citizen of the language.
4. Dynamically adding and modifying properties in classes and objects with the "monkey patching" mechanism.
5. Extending existing higher-level types into more specialized subtypes.

Learning objectives

After this module, students can be given a simple toy model concept in the style of "bank account" or "animal", and they could list some methods that would be verbs associated with the concept in the problem domain. They are able to write that concept as a Python class with the appropriate methods `__init__` and `__str__`, along with the methods that correspond to those chosen verbs. They would know how to look up which magic method corresponds to the language operator that they would like to work with that data type, and implement that magic method in that class. They can explain the dynamic nature of Python as names existing inside the objects, and how this reality naturally allows some methods to be "monkey patched" to behave differently just for one object as they do for other instances of that class.

Readings

1. "Python Lecture Notes", sections "11.1: Thinking in abstractions instead of implementations", "11.2. Defining your own classes", "11.3. Naturalized citizens of Pythonia", "11.4. Patching in new properties", "11.5. Subtyping existing concepts", "11.6. Multiple inheritance"
2. GitHub repository `ikokkari/PythonExamples`: `cards.py` `temperature.py` `shape.py`
3. YouTube playlist "CCPS 109 Computer Science I, Python" videos: "Python 11-1: Brothers from the same mold"

Lab problems

Again, since the problem collection "109 Python Problems for CCPS 109" was designed so that each problem could be solved using only the core Python language (sometimes with a sprinkle of recursion, but only for those problems that actually ain from it), it contains no problems where you would have to define your own data types for complex concepts. Instead, the last three problems chosen for their educational value continue on the theme of text strings.

1. Longest palindrome substring (`longest_palindrome`)

2. Brangelina (`brangelina`)
3. Autocorrect for stubby fingers (`autocorrect_word`)