

Lecture notes in Bioinformatics and Programming

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Preface

This is a Quarto book.

To learn more about Quarto books visit <https://quarto.org/docs/books>.

1 Before you begin

This chapter serves to get the practicalities out of the way so you can start programming. Read the whole chapter once carefully before you install anything

Install Python

In this course, we use the Python programming language, and we need the Python program to run the code we will write. We will use a distribution of Python called *Anaconda*. Anaconda is the easiest way of installing Python on Windows, macOS (Mac), and Linux. To install Anaconda, head to this site. Click “Download”. When the download has completed, double-click the file you just downloaded and follow the instructions on the screen. It is important that you accept all the suggested installation settings.

The text editor

You will also need a *text editor*. A text editor is where you write your Python code. For this course, we will use *Visual Studio Code* - or *VScode* for short. You can download it from this page. If you open *VScode*, you should see something like Figure 1.1. You may wonder why we cannot just Word to create and edit files with programming code. The reason is that a text editor made for programming, such as *VScode*, only saves the actual characters you type. So unlike, Word, it does not silently save all

kinds of formatting, like margins, bold face text, headers, etc. With VS-code, what you type is *exactly* what ends up in the file when you save it. In addition, where Word is made for prose, VScode is made for programming and has a lot of features that you will make your programming life easier.

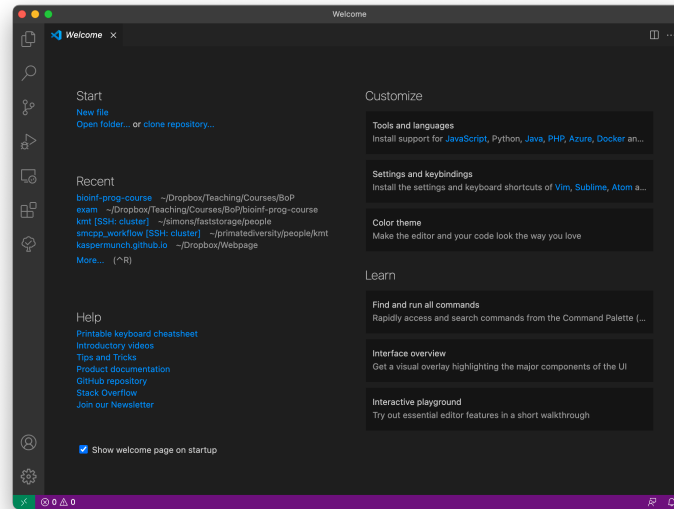


Figure 1.1: Visual Studio Code (VScode)

The terminal

The last thing you need is a tool to make Python run the programs you write. Fortunately, that is already installed. On **OSX** this is an application called *Terminal*. You can find it by typing “Terminal” in Spotlight Search. When you start you will see something like Figure 1.2. You may be presented with the following text:

The default interactive shell is now zsh.
To update your account to use zsh, please run ``chsh -s /bin/zsh``.
For more details, please visit <https://support.apple.com/kb/HT208050>.



Figure 1.2: The Terminal app on Mac

Do ***not*** update your account ***after*** you install Anaconda (see below). If you do, *Terminal* will not be able to find the Anaconda Python (If you did so by mistake anyway, you change back using this command: `chsh -s /bin/bash`).

On **Windows** the tool you need is called the *Anaconda Powershell Prompt* and was installed along with Anaconda Python. You should be able to find it from Start menu. Make sure you open *Anaconda Powershell Prompt* and **not** *Anaconda Powershell Prompt*. They are different programs. If you open *Anaconda Powershell Prompt* you should see something like Figure 1.3.

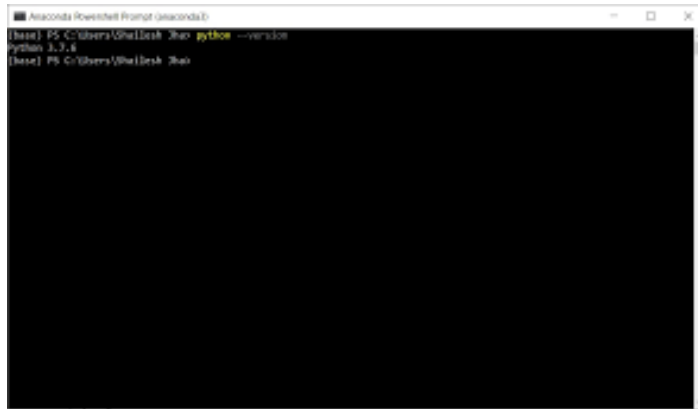


Figure 1.3: Anaconda Powershell Prompt app on Windows

What is *Anaconda Powershell Prompt* and this *Terminal* thing, you ask. Both programs are what we call *terminal emulators*. They are programs used to run other programs, like the ones you are going to write yourself. I will informally refer to both *Terminal* and *Anaconda Powershell Prompt* as “the terminal”. So if I write something like “open the terminal”, you should open *Anaconda Powershell Prompt* if you are running Windows and the *Terminal* application if you are running OS X.

The terminal is a very useful tool. To use it, however, you need to know a few basics. First of all, a terminal lets you execute commands on your computer. You simply type the command you want and then hit enter. The place where you type is called a prompt (or command prompt) and it may look a little different depending on which terminal emulator you use. In this book we represent the prompt with the character \$. So a command in the examples below is the line of text to the left of the \$. When you open the terminal you’ll be located in a folder. You can see which folder you are in by typing `pwd`, and then press Enter on the keyboard. When you press Enter you tell the terminal to execute the command you just wrote. In this case, the command you typed simply tells you the path to the folder we are in. If I do it I get:

```
$ pwd
/Users/kasper/programming
```

If I had been on a windows machine it would have looked something like:

```
$ cd
C:\Users\kasper\programming
```

So right now I am in the folder programming. /Users/kasper/programming is the path or “full address” of the folder with dashes (or backslashes on windows) separating nested folders. So programming is a subfolder of kasper which is a subfolder of Users. That way you not only know which folder you are in but also where that folder is. Let us see what is in this folder. You can use the ls command (l as in Lima and s as in Sierra). When I do that and press Enter I get:

```
$ ls
notes projects
```

It seems that there are two other folders, one called notes and another called projects. If you are curious about what is inside the notes folder, you can “walk” into the folder with the cd command. To use this command you must specify which folder you want to walk into (in this case notes). We do this by typing cd, then a space and then the name of the folder. When I press enter I get:

```
$ cd notes
$
```

It seems that nothing really happened, but if I run the pwd command now to see which folder I am in, I get:

```
$ pwd
/Users/kasper/programming/notes
```

Just to keep track of what is happening: before we ran the `cd` command we were in the directory `/Users/kasper/programming` folder, and now we're in `/Users/kasper/programming/notes`. This means that we can now use the `ls` command to see what is in the notes folder:

```
$ ls
$
```

Again it seems like nothing happened. Well, `ls` and `dir` do not show anything if the folder we are in is empty. So notes must be empty. Let us go back to where we came from. To walk “back” or “up” to `/Users/kasper/programming` we again use the `cd` command, but this time we do not need to name a folder. Instead, we use the special name `..` to say that we wish to go to the parent folder called `programming`, i.e. the folder we just came from:

```
$ cd ..
$ pwd
/Users/kasper/programming
```

Now when we run the `pwd` command we see that we are back where we started. Let us see if the two folders are still there:

```
$ ls
notes projects
```


They are!

Hopefully, you are now able to use navigate your folders and see what is in them. You will need this later to go to the folders with the code you write for the exercises and projects during the course.

| Action | OSX |
|-------------------------|-----------------------|
| Show current folder | <code>pwd</code> |
| List folder content | <code>ls</code> |
| Go to subfolder “notes” | <code>cd notes</code> |
| Go to parent folder | <code>cd ..</code> |

Create a conda envirionment for the course

In bioinformatics, we install packages and programs so we can use them in our analyses and pipelines. Sometimes, however, the versions of packages you need for one project conflicts with the versions you need for other projects that you work on in parallel. Such conflicts seem like an unsolvable problem. Would it not be fantastic if you could create a small insulated world for each project, which then only contained the packages you needed for that particular project?. If each project had its own isolated world, then there would be no such version conflicts. Fortunately, there is a tool that lets you do just that, and its name is Conda.

“ Conda is an open source package management system and environment management system for installing multiple versions of software packages and their dependencies and switching easily between them. ”

The small worlds that Conda creates are called “environments”. You can create as many environments as you like, and then use each one for a sep-

arate bioinformatics project, a course, a bachelor project, or whatever you would like to insulate from everything else. Conda also downloads and installs the packages for you and it makes sure that the software packages you install in each environment are compatible. It even makes sure that packages needed by packages (dependencies) are also installed. Conda is truly awesome.

When you install Anaconda, Conda makes a single base environment for you. It is called “base” and this is why it says “(base)” on your terminal.

In this course, you need to install programs, and python libraries that could conflict with the packages you need for other courses or future projects. So we will create an isolated Conda environment for Bioinformatics and Programming to avoid such conflicts. Conda is a program you run from the command line, just like python or cd. So open your terminal (i.e., the “Terminal” program if you are on a Mac and the “Anaconda Powershell Prompt” program if you are on Windows). Now copy/paste these command lines into the terminal *one at a time* and press return (enter) after pasting each one:

```
conda create -y -n bioprogram
conda activate bioprogram
conda config --env --add channels conda-forge
conda config --env --add channels sepandhaghighi
conda config --env --add channels kaspermunch
conda install -y 'python=3.9' pygments textual rich art bp-help
```

These commands run the Conda program and tell it to create a new environment with name “bioprogram” and to install the packages we need in that environment. Once you hit enter on the last command, Conda works for some time and then writes a long list of packages in your terminal. These are all the packages and dependencies required in versions that all fit together.

Notice how the command prompt changed from “(base)” to “(bioprog)” to show that you are now in the bioprog environment. Looks like nothing changed, but now you have access to terminal commands not available in the base environment. You will learn about these later. Try this command:

```
conda deactivate
```

Notice how it now again says “(base)” on your command prompt. That is because you are back in your base environment. Every time you start a new terminal window, you will need to run `conda activate bioprog` to activate the environment to be able to access the course tools.

You are all set

Well done! You are all set to start the course. Have a cup of coffee and look forward to your first program. While you sip your coffee, I need to you take an oath (one of three you will take during this course). Raise your right hand! (put the coffee in your left).

“ **Oath 1:** I swear *never* to copy and paste code examples from this book into my text editor. I will always *read* the examples in then *type* them into my editor. ”

This serves three purposes (as if one was not enough):

1. You will be fully aware of each and every bit of each example.
2. You will learn to write code correctly and without omissions and mistakes.
3. You will get Python “into your fingers”. It sounds silly, but it *will* get into your fingers.

2 Writing a program

Lets get you started...

Hello World

Dive in and make your first program. Begin by creating a new file in your editor (*VScode*) and save it as `hello.py`. The `.py` suffix tells your editor that this file contains Python code. As you will see, this makes your life a whole lot easier. Such a file with Python code is usually called a *script*, but we can also call it a program.

Now write *exactly* this in the file (`hello.py`):

```
print("Hello world")
```

Your editor will color your code a little differently, but that is not important. Save your file with the added code, and you have your first program! Of course, there is not much point in having a program if it just sits there on your computer. To run your program, do the following:

1. Open the terminal and navigate to the folder (directory) where you saved `hello.py`. Use the `cd` command to do so. If you do not remember how, go back and read the previous chapter again.
2. Type `python hello.py` in the terminal and hit Enter.

A screenshot of a macOS-style terminal window. The title bar at the top shows three colored window control buttons (red, yellow, green) on the left, and a home icon followed by the text 'bash /Users/das — bash — 80x24' on the right. The terminal content shows a prompt 'bash-3.2\$' followed by the command 'python hello.py'. The output 'Hello world' is displayed on the next line. Below the output, the prompt 'bash-3.2\$' is shown again with a cursor, indicating the command has completed and the user is ready for the next input.

```
bash-3.2$ python hello.py
Hello world
bash-3.2$
```

Figure 2.1: Hello world

You should see something like Figure 2.1.

This is where you shout “it’s alive!”, toss your head back and do the insane scientist laugh.

Okay, what just happened? You wrote a program by creating a file in which you wrote one line of code. You then ran the program using Python and it wrote (printed) `Hello world` in the terminal. Do not worry about the parentheses and quotes for now and just enjoy your new life as a programmer.

Maybe you wonder why we write `print` and not `w r i t e` or something else? That actually goes all the way back to the days when computers were big clunky things with no screens attached. They could only interact with the user by *printing* out things on a real physical paper printer. Back then, the output you now see on the screen was printed onto a piece of paper that the programmer could then look at. These days `print` shows up in the terminal, but the story should help you remember that `print` spits text *out of your program* just like a printer.

Now try to add another line of code like this:

```
print("Hello world")
print("I am your first program")
```

Save the file and run it again by typing `python hello.py` in your terminal and hit Enter.

You should see this:

```
Hello world
I am your first program
```

Now your program first prints `Hello world` and *then* it prints `I am your first program`. The *then*-part is important. That is how a Python program

works. Python (the python you write in front of hello.py) reads your hello.py file and then executes the code, one line after another until it reaches the end of the file.

This is essential, so read that paragraph again. Now read it once more. It may seem trivial, but it is absolutely fundamental always to remember that this is how Python runs your code. So here is oath 2:

“ **Oath 2:** I swear always to remember that each line of code in my script is executed one after another, starting from the first line in the script and ending at the last line. ”

When you write Python code, you always follow this workflow:

1. Change the code in the file.
2. Save the file.
3. Execute the code in the file using the terminal.
4. Start over.

Make sure you get the hang of this in the following exercises.

Important: The examples and exercises in this course are designed to work if you execute your scripts from the folder they are stored in. So you must navigate into the relevant folder before you execute your script. If your script is called hello.py, you must *always* execute it exactly like this: `python hello.py`. On some computers it is possible to just type hello.py without python in front of it. Do *not* do that. Also, do *not* “drag” the script file into the Terminal either.

Exercise 2-1

Try to swap the two lines of code in the file and run the program again. What does it print now?

Exercise 2-2

Try to make the program print a greeting to yourself. Something like this:

Hello Sarah!

– if your name is Sarah, of course.

Exercise 2-3

Add more lines of code to your program to make it print something else. Can you make your program print the same thing ten times?

Error Messages

Did you get everything just right with your first program or did you get error messages when you executed your code with python? Maybe you wrote the following code (adding an extra closing parenthesis):

```
print("Hello world"))
```

– and then got an error like this:

```
File "hello.py", line 1
  print('Hello world'))
                        ^
SyntaxError: invalid syntax
```

This is Python's way of telling you that the `hello.py` script has an error in line 1. If you write something that does not conform to the proper syntax for Python code then you will get a `SyntaxError`. Python will do its best to figure out where the problem is and point to it with a `^` character.

You will see many such error messages in your new life as a programmer. So it is important that you practice reading them. At first, they will be hard to decipher, but once you get used to them, they will help you quickly identify where the problem is. If there is an error message that you do not understand the internet is your friend. Just paste the error message into Google's search field, and you will see that you are not the only one out there getting started on Python programming. It is okay if you do not know how to fix the problem right now, but it is essential to remember that these error messages are Python's way of helping you understand what you did wrong.

Exercise 2-4

Try to break your new shiny program and make it produce an error message when you run it. An easy way of doing this is to remove or change random characters from the program. If you run this (with a missing end-parenthesis:

```
print("Hello world"  
print("I am your first program")
```

You will get this error

```
File "hello.py", line 2  
    print("I am your first program")  
    ^  
SyntaxError: invalid syntax
```

The `^` character tells you when your code stopped making sense to Python. Some times that is a bit after where you made your mistake.

Try to make other kinds of errors. Which error messages do you see? Do you see the same error message every time, or are they different? Try googling the error messages you get. Can you figure out why the change you made broke the program? How many different error messages can you produce?

Strings

In programs, text values are called *strings*, and you have already used strings a lot in your first program. A string is simply a piece of text, but we call it a string because it is a “string of characters”. In Python, we represent a string like this:

```
"this is a string"
```

or like this:

```
'Hello world'
```

That is, we take the text we wish to use as our value, and we put quotes around it. We are allowed to use either double quotes (the first example) or single quotes (the second example). We can mix them like this:

```
print('this is "some text" with a quotes')
```

– but not like this:

```
print("this is a broken string')
```

Can you see why, and how it is handy to have both single and double quotes? Well, if we did not have both, we could not have text with quotes in it. You just need to remember to use the same kind of quotes at each end of the string. Running the latter example gives an error message telling you that Python cannot find the quote that was supposed to end the string:

```
File "broken.py", line 1
    print("this is a broken string')
                                   ^
```

SyntaxError: EOL while scanning string literal

It is Python's way of saying: "I got to the end of the line (EOL) without finding an matching end quote".

Comments

You have already learnt that Python reads and executes one line of code at a time until your program has no more lines of code.

However, we can make a line invisible to Python by putting a # symbol in front of it, like this:

```
# print("Hello world")
print("Greetings from your first program")
```

When you do that, Python simply does not read that line. It is not part of the program. Run the program again. You will notice that now only the second line is part of your program:

```
$ python hello.py
Greetings from your first program
```

This is useful in two ways:

1. It lets you disable certain lines of your code, by keeping Python from reading them. For example, you may want to see what happens if that line of code was not executed to understand how your program works.
2. It allows you to write notes in your code Python to help you remember how your code works.

Lines with a # in front are called “comments” because we normally use them to write comments about the code we write. If you ask for help about some problem, you will often hear your instructor say: try to “comment out” line two. When your instructor says that, it simply means that you should add a # in front of line two to see what then happens.

Exercise 2-5

What happens if I put a # in the middle of a line of code? Try it out!

Exercise 2-6

Try this:

```
# Note to self: the lines below print stuff
print("Hello world")
print("Greetings from your first program")
```

Exercise 2-7

Try this:

```
print("Hello world") # actually, everything after a # is ignored
print("Greetings from your first program")
```

What did you learn? Which parts of each line are considered part of the program?

Exercise 2-8

Now try this:

```
print("Hello # world")
print("Greetings from your first program")
```

What did you learn about # characters in strings? ##### Exercise Try this:

```
print("Hello world"#)
print("Greetings from your first program")
```

Did you expect this to work? Why? Why not? What error message did you get?

3 Dealing with values

This chapter is about values and variables, the two most central concepts in programming.

Math

Much programming is done to compute stuff. In Python the usual math operations are done using these arithmetic operators:

| Operator | Operation |
|----------|--------------------|
| + | plus |
| - | minus |
| / | division |
| // | integer division |
| * | multiplication |
| ** | exponentiation |
| % | modulo (remainder) |

You are probably quite familiar with these - except perhaps for integer division, exponentiation and modulo. Let us take some of the operators for a spin. Remember to carefully write the whole thing in an empty file in *VScode*. Do *not* copy-paste. Then save the file as `mathandlogic.py` and run it from the terminal. Do not call your file `math.py`. It may bite you later. Just trust me on that one.

```
print("Four times two is", 4 * 2)
```

Notice how you can print more than one thing at a time if you put commas between the values you want to print? We can group computations using parentheses, just like in normal math. Try this:

```
print("10 / (2 + 3) is", 10 / (2 + 3))  
print("(10 / 2) + 3 is", (10 / 2) + 3)
```

In addition to the regular math operators, there are a few extra operators that we call *comparison operators* because they are used to compare two values, e.g. two numbers.

| Operator | Operation |
|----------|-----------------------|
| < | less-than |
| > | greater-than |
| <= | less-than-or-equal |
| >= | greater-than-or-equal |
| == | equal |
| != | not equal |

Try this:

```
print("Is 5 greater than -2?", 5 > -2)  
print("Is 5 greater or equal to -2?", 5 >= -2)  
print("Is 5 less or equal to -2?", 5 <= -2)  
print("Is 5 less than 7 - 2?", 5 < 7 - 2)  
print("Is 5 equal to 7 - 2?", 5 == 7 - 2)
```

As you may have noticed running this code, comparing things using these operators we always produce either True or False. E.g. the following


```
print(5 < 7)
```

prints the value True, because 5 *is* actually smaller than 7. True and False are special values in Python that we can use (and print if we like) just like any other Python value:

```
print(True)
print(False)
```

Exercise 3-1

Try to write and run the code below. Compare each line to what is printed when you run the code. Make sure you understand why.

```
print("I have", 25 + 30 / 6, "of something")
print("I have", 100 - 25 * 3 % 4, "of something else")

print("Is it true that 3 + 2 < 5 - 7?")
print(3 + 2.1 < 5.4 - 7)

print("3 + 2.1 is", 3 + 2.1)
print("5.4 - 7 is", 5.4 - 7)

print("Oh, that's why it's False.")
```

Exercise 3-2

There is even an additional comparison operator that tests if something is a part of something else. That operator is called in. One use of it is to

to test if one string is part of another string. Try this to figure out how it works:

```
print("Hell" in "Hello world")
print("Hello world" in "Hello world")
print("Hello world" in "Hell")
print("lo wo" in "Hello world")
print("Artichoke" in "Hello world")
```

Exercise 3-3

Say the supermarket has chocolate bars for 7 kr. Write a small Python program (in a file called `chocolate.py`) that prints how many chocolate bars you can get for your 30 kr. You should run it like this;

For example, it could output something like this:

```
$ python chocolate.py
```

to have it print something like this:

I can buy 4.285714285714286 chocolate bars!

Exercise 3-4

We mentioned a special operator called *modulo*. Google it you do not remember what it does. How about *integer division*. Explain both to a fellow student (or to yourself out loud).

Exercise 3-5

You obviously cannot go buy 4.3 chocolate bars in a store. You will have to settle for 4. Can you change the program you made in Section 3-3 to print the number of bars you can actually buy, and the change you then have left? Use the modulo and integer division operators. Something like:

I can buy 4 chocolate bars leaving me with 2 kr in change

Exercise 3-6

What happens if you try to run the following program?

```
print( 1 / 0 )
```

If you get an error? What kind of error? Why do you think you get that error? Does it make sense?

Exercise 3-7

You have probably know the Pythagorean theorem for computing the hypotenuse (the longest side) of a right-angled triangle. The Pythagorean theorem looks like this: $a^2 + b^2 = c^2$. Here c is the length of the hypotenuse and a and b are the lengths of the two legs of the triangle. So if we have a triangle where $a = 5$ and $b = 2$ and we want to find c^2 we can do this in Python:

```
print("The squared length of the hypotenuse is:", 5**2 + 2**2)
```

Exercise 3-8

However, we are rarely interested in the *squared* length of the hypotenuse. Can you modify the code you wrote in Section 3-7 so you compute c instead of c^2 ? Taking the square root of a number is the same as taking that number and exponentiating it to 0.5, so the square root of x is $x^{0.5}$. Do you know of a Python operator that does exponentiation?

Logic

Now you know how to use the comparison operators to produce a True or False value. There are three additional operators that let you express more elaborate “True/False” statements than with the comparison operators alone. These are the *logical* operators: and, or and not.

Exercise 3-9

Go through the code below and see if you can figure out what each line does. Then write the code into your editor and run it to see what actually happens.

```
print(2 < 3)
print(10 < 12)
print(8 > 100)
print(2 < 3 and 10 < 12)
print(8 > 100 and 2 < 3)
print(8 > 100 or 2 < 3)
print(not 8 > 100 and 2 < 3)
print(not 8 > 100 and not 2 > 3)
```

Did it do what you expected? Can you explain each line?

Exercise 3-10

When exposed to the operators `and`, `or` and `not`, some values are considered true and others are considered false. What happens when you put `not` in front of something that is considered true or false? Decide what you think and why before you write the code and try it out.

```
print(not True)
print(not False)
print(not 0)
print(not -4)
print(not 0.0000000)
print(not 3.14159265359)
print(not "apple")
print(not "")
```

From the code above, try to find out which values Python considers true and which it considers false. Can you come up with a rule?

Exercise 3-11

The logical operator `and` takes two values (the one to the left of the operator and the one to the right) and figures out whether *both* the left and the right expression is true. It actually boils down to this:

| Left expression | Right expression | Result |
|-----------------|------------------|--------|
| True | True | True |
| True | False | False |
| False | True | False |
| False | False | False |

Write some code to confirm that the table above is correct using Python. For example, to test the first case, do this:

```
print(True and True)
```

Exercise 3-12

Python will not do any more work than absolutely necessary to find out if a logical expression is true or not. That means that, if the value left of and is considered false by Python, then there is no reason look at the right value, since it is already established that they are not *both* considered true. In this case the expression reduces to the *left* value. I.e. False and True reduces to False.

If the value left of and is considered *true* by Python, then Python needs to look at the right value too to establish if they are *both* considered true. In this case the expression reduces to the value on the *right*. I.e. True and False reduces to False.

A rule-of-thumb is that the whole expression reduces to the last value that Python needs to consider to decide if the whole expression is true or false. Use that rationale to explain to yourself how the two last combinations in Section 3-11 are evaluated.

Exercise 3-13

Like the and operator, the or operator also takes two values. However, the or operator tries to figure out whether *one* of the two values are true. Thus, the or operator boils down to this:

| Left expression | Right expression | Result |
|-----------------|------------------|--------|
| True | True | True |
| True | False | True |
| False | True | True |
| False | False | False |

Write some code to confirm that the table above is correct using Python. For example, to test the first case, do this:

```
print(True or True)
```

Exercise 3-14

As with the `and` operator, Python will not do any more work than absolutely necessary when evaluating an expression with `'or'`. So if the value left of `or` is considered true by Python, then there is no reason look at the right value, since it is already established that at least *one* of them are considered true. In this case the expression reduces to the *left* value. I.e. `True or False` reduces to `True`.

If the value left of `or` is considered *false* by Python, then Python still needs to look at the right value to establish if at least one of them are considered true. In this case the expression reduces to the *right* value. I.e. `False or True` reduces to `True`.

Again, the whole expression reduces to the last value that Python needs to consider to decide if the whole expression is true or false. Use that same rationale to explain to yourself how the two last combinations in Section 3-13 are evaluated.

Exercise 3-15

Remember what you learned in Section 3-10 about which values are considered true and which are considered false. Combine that with what you learned in Section 3-11 and Section 3-13 about what logical expressions reduce to and see if you can figure out what is printed below and why. Use the rule-of-thumb from Section 3-14. Decide what you think before you write the code and try it out.

```
print(True and 4)
print(0 and 7)
print(-27 and 0.5)
print(42 and 0)
print("apple" and "orange")
print("apple" and "")
print(42 or 0)
print("apple" and "")
print("apple" or "")
```

If you were surprised what was printed, maybe go back and have a look at Section 3-11 and Section 3-13 again.

Exercise 3-16

Recall the `in` operator from Section 3-2? There is also an operator called `not in`. I guess you can imagine what that tests. Try it out.

Variables

“ By now you probably feel the first signs of brain-overload. If you do not take breaks, your brain may overheat and explode - we have seen that happen. One of the nice things about the brain is that it works when you rest. Archiving and understanding a lot of new information takes time, and force-feeding your brain will not help. The last part of this chapter is very important so now might be a good time for a good long break. ”

This section is about *variables* and this is where the fun begins. A variable is basically a way of assigning a name to a value. 8700000 is just a value, but if we assign a name to it then it gets a special meaning:

```
number_of_species = 8700000
print(number_of_species)
```

In this case, the variable `number_of_species` represents the estimated number of eukaryotic species on the planet, which is 8700000. So 8700000 is the *value* and “`number_of_species`” is the variable name. Write the code above into a file and run it. Notice how this lets us refer to the *value* using the *variable name*. What appears in the terminal when you do that? do you see `number_of_species` or 8700000?

As you can see in the small program above, one of two different things happens when a variable name appears in Python code:

- **Assignment:** When a variable name appears to the left of an equals sign, then a value is assigned to the variable. This is what happens in the first line where `number_of_species` is *assigned* the value 8700000.

- **Substitution:** In all other contexts, the variable is substituted for its value. This is what happens in the second line where Python *substitutes* the variable name `number_of_species` for its value `8700000` and then prints that.

That is basically it, but let us take the example a bit further and create another variable that we assign the value `1200000` to. That is the number of species discovered so far. Now, let's add this to the program and use it to compute the number of species we have yet to identify. Start by reading the code below super carefully. Remember that a variable is *either* assigned a value or substituted for the value it represents. For each occurrence of the variables below, determine if they are being assigned a value or if they are substituted for their value.

```
number_of_species = 8700000
number_discovered = 1200000
number_unidentified = number_of_species - number_discovered
print(number_unidentified)
```

Now write the code into a file and run it. Take some time to let it sink in that variables are extremely useful for two reasons:

1. Variables give meaning to a value. Without the variable name, the value `1200000` could just as well be the number of people that lives in Copenhagen. However, by giving the value a meaningful name, it becomes clear what the value is meant to represent.
2. We can assign new values to variables (that is why they are called *variables*). That way we can change the value of `number_discovered` as new species are discovered.

Your variable names can be pretty much anything, but they have to start with a letter or an underscore (`_`) and the rest of the name has to be either letters, numbers or underscores. Just to be clear: a space is *not* any of

those things, so do not use spaces in variable names. Above all, be careful in your choice of variable names. Variable names are case sensitive, meaning that count and Count are two different variables. Stick to lower case variable names. That makes your code easier to read.

Exercise 3-17

For each occurrence of the variables below, determine if they are being assigned a value or if they are substituted for their value.

```
breeding_birds = 4
print(breeding_birds)
breeding_birds = 5
print(breeding_birds)
```

Exercise 3-18

For each occurrence of the variables below, determine if they are being assigned a value or if they are substituted for their value.

```
breeding_birds = 4
print(breeding_birds)
breeding_birds = breeding_birds + 1
print(breeding_birds)
```

Exercise 3-19

What happens if you take the first example in this section swap the two lines? So going from this:

```
number_of_species = 8700000
print(number_of_species)
```

to this:

```
print(number_of_species)
number_of_species = 8700000
```

Explain to yourself what happens in each line of each version of the program. What kind of error do you get with version two and why? Remember Oath 2!

Exercise 3-20

Write the following code in a file, save it and run it.

```
income = 45000
taxpercentage = 0.43
tax_amount = tax_percentage * income
income_after_tax = income - tax_amount
print('Income after tax is', income_after_tax)
```

You should get an error that looks a lot like this one:

```
Traceback (most recent call last):
  File "tax.py", line 3, in <module>
    tax_amount = tax_percentage * income
NameError: name 'tax_percentage' is not defined
```

It says that the error is on line 3. Can you figure out what is wrong? Hopefully, you will now appreciate how much attention to detail is required

when programming. Every tiny, little symbol or character in your code is *essential*.

Different types of values

By now you probably have a pretty good idea about what a value in Python is. So far you have seen text like 'Banana', integers like 7 and numbers with a fractional part like 4.25.

In Python, a text value is a *type* of value called a *string* which Python denotes `str` (abbreviation for “string”). So 'Banana' is a string, and so is 'Banana split'. There are two types of numbers in Python. Integers (like 7, 42, and 3) are called `int`. Numbers with a fractional part (like 3.1254 and 4.0) are that are called `float` (abbreviation for “floating-point number”).

As I mentioned earlier, `True` and `False` are Python values too. They are called booleans or `bool`, named after an English mathematician called George Boole famous for his work on logic.

So the different *types* of values we know so far are:

| Name | Type in Python | Examples |
|----------------|-----------------------|--|
| String | <code>str</code> | "hello", '9' |
| Integer | <code>int</code> | 0, 2721, 9 |
| Floating-point | <code>float</code> | 1.0, 4.4322 |
| Boolean | <code>bool</code> | <code>True</code> , <code>False</code> |
| None | <code>NoneType</code> | <code>None</code> |

In case you did not notice, I added a special type at the end that can only have the value `None`. I may sound a little weird, but in programming, we

sometimes need a value that represents nothing, or None. For now, just make a mental note that None is also a Python value.

When you do computations in Python it is no problem to mix integers and floating-point numbers. Try this:

```
print("What is 0.5 * 2?", 0.5 * 2)
print("What is 3 / 2?", 3 / 2)
```

As you can see we can also make computations using only integers that result in floating-point numbers.

Some of the math operators not only work on numbers, they also work on strings. That way you can add two strings together. It is no longer math of course - but quite handy.

```
fruit = 'Ba' + 'na' + 'na'
print(fruit)
```

Exercise 3-21

If you try to combine different types of values in ways that are not allowed in Python, you will get an error. Try each of the following weird calculations in turn, and read the each error message carefully.

```
x = 3 - '1.5'
print(x)
```

```
x = None - 4
print(x)
```

Exercise 3-22

Write these two examples and compare the resulting values of x

```
x = '9' + '4'  
print(x)
```

```
x = 9 + 4  
print(x)
```

Exercise 3-23

Try these two examples. What happens in each case? Does it make sense?

```
x = '72' * 3
```

```
x = '72' * '3'
```

Exercise 3-24

Will this work? Use what you have learned from the other exercises and try to predict what will happen here. Then write the code and try it out.

```
x = 'Ba' + 'na' * 2  
print(x)
```

Exercise 3-25

Sometimes you may need to change a string to a number. You can do that like this:

```
some_value = "42"  
other_value = int(some_value)
```

Write some code that converts strings to numbers and numbers to strings. Remember that numeric values are either integers or floats. Use `int`, `float` as in the example above. You will notice that only meaningful conversions work. E.g. this will not work: `number = int('four')`. To convert a number to a string you can use `str`

Having completed the above exercises you should take note of the following four important points:

1. All Python values have a type. So far you know about strings, integers, floating-points, and booleans.
2. Math operators let you do cool things like concatenating two strings by adding them together.
3. The flip side of that cool coin is that Python will assume you know what you are doing if you add two strings ('4' + '4' is '44' *not* 8) or multiply a string with an integer ('4' * 4 is '4444' *not* 16).
4. You can change the type of a value. E.g '4' to 4 or 1 to 1.0.
5. Python will throw a `TypeError` if you try to combine types values of values in ways that are not allowed.

“ **Escape characters:** An escape character is a backslash \ followed by a single character. In Python, the most commonly used ones are `\n` and `\t`. ”

Exercise 3-26

What do you think is printed here?

```
main_course = 'Duck a la Banana\n'  
dessert = 'Banana split\n'  
menu = main_course + dessert  
print(menu)
```

Can you figure out what the special character `\n` represents?

Exercise 3-27

What do you think is printed here?

```
dish_one = 'Banana\t\tsplit'  
dish_two = 'Chocolate\tcake'  
print(dish_one)  
print(dish_two)
```

Can you figure out what the special character `\t` represents?

Mixed exercises

Each chapter in the book ends with a set of mixed exercises that are meant to give you an opportunity to combine what you have learned so far. In this case, they are meant to train your familiarity with the following topics:

- Strings
- Math

- Logic
- Types of values
- Variables

Exercise 3-28

What happens if you try to run the following program?

```
print("What happens now?", 1 / )
```

If you get an error, why do you think you get that error?

Exercise 3-29

What happens if you try to run the following program?

```
print("What happens now?", 1 / 3
```

If you get an error, why do you think you get that error? Can you fix it?
(Hint: EOF is short for End Of File)

Exercise 3-30

Determine, for each or the eight occurrences of the variable `x` below, where it is being assigned a value and when it is substituted for its value:

```
x = 1
x = x + 1
x = x + 1
x = x + 1
```

```
print(x)
```

Then figure out what is printed and why (remember oath 2). What value does `x` represent at each occurrence in the code?

Exercise 3-31

Some comparison operators also work with strings. Consider this code:

```
print("apples" == "pears")
```

What is printed here? Write the code and see for yourself once you think you know. If you were wrong, make sure you understand why.

Exercise 3-32

Consider this code:

```
print('aaaaaa' < 'b')
print('a' < 'b')
print('aa' < 'ab')
print('99' > '100')
print('four bananas' > 'one banana')
```

What is printed here? Write the code and see for yourself once you think you know. By what rule does Python decide if one string is smaller than an other? If you have looked something up in an encyclopedia recently, you may have a clue. Also try to google “ASCII table”.

Exercise 3-33

Consider this code:

```
print('banana' < 'Banana')
```

What is printed here? Write the code and see for yourself once you think you know.

Exercise 3-34

Do you think it is allowed to use relational operators on values of different types? Try these out and see for yourself:

```
print('Banana' > 4)
```

```
print('42' == 43) # this one is dangerous...
```

```
print(4 in '1234')
```

Practice reading this kind of error (TypeError).

Exercise 3-35

Can you use the in operator to test if this mini gene is part of the DNA string?

```
mini_gene = 'ATGTAG'  
dna_string = 'GCTATGTAGGTA'
```

Exercise 3-36

Say you have two strings "4" and "2". What happens if you add them like this: "4" + "2". Can you convert each one to integers so you get 6 when you add them? (have a look at Section 3-25 if you do not remember).

Exercise 3-37

What happens if you run this code? Do you get an error? Do you remember why?

```
1value = 42
```

Exercise 3-38

What happens if you run this code?

```
print('Hi')  
print('Hi')  
print('Hi')
```

Compare to what happens when you run this code:

```
print('Hi\nHi\nHi')
```

Do you remember what \n represents? What does it tell about what is added at the end every time you print something?

Exercise 3-39

Make three exercises for your fellow students. See if you can make them so they test the understanding of (almost) all you have learned so far.

4 The order of events

This chapter is about how Python interprets (or evaluates) the code you write. It has a few fancy long words that may seem foreign to you. Do not let that throw you off. They are all just fancy names for something very simple.

Precedence of Operators

Fear not. Precedence is just a nasty word for something we have already talked about. Precedence simply specifies that some things are done before other things – or more correctly, that some operations are performed before others. You already know that multiplication is done before addition. Another way of saying that is that multiplication *takes precedence* over addition. The expression below obviously reduces to 7 in two steps:

$$1 + 3 * 2$$

First, $3 * 2$ reduces to 6 and then $1 + 6$ reduces to 7. If we wanted to add 1 and 3 first we would need to enforce this by adding parentheses:

$$(1 + 3) * 2$$

This is because the multiplication operator (*) has higher precedence than the addition operator (+). Here is the list of the most common operators and their precedence in Python:

| Level | Category | Operators |
|---------|---------------------|----------------------------------|
| Highest | exponent | ** |
| | positive / negative | +x, -x |
| | multiplication | *, /, //, % |
| | addition | +, - |
| | relational | !=, ==, <=, >=, <, >, in, not in |
| | logical | not |
| | logical | and |
| Lowest | logical | or |

Sometimes a statement contains adjacent operators with the same precedence. In this case Python evaluates the expression left to right. I.e. This following expression first reduces to 0.5 * 2 and then to 1

```
2 / 4 * 2
```

The following one first reduces to 1 * 4 and then to 4:

```
2 / 2 * 4
```

If you want Python order the operations in any other way, you need to use parentheses (E.g. 2 / (2 * 4)).

Exercise 4-1

Look at each expression in the exercises below and use the table above to decide if it evaluates to True or False. Then write the code and test if you were right. If not figure out why.

```
2 + 4 * 7 == 2 + (4 * 7)
```


Exercise 4-2

Does this reduce to True or False?

```
4 > 3 and 2 < 1 or 7 > 2
```

Exercise 4-3

Does this reduce to True or False?

```
4 > 3 and (2 < 1 or 7 > 2)
```

Exercise 4-4

Does this reduce to True or False?

```
2 * 4 ** 4 + 1 == (2 * 4) ** (4 + 1)
```

Statements and Expressions

To be able to talk concisely about programming (and to receive more useful help from your instructors) you need a bit of vocabulary. *Statements* and *expressions* are two such words that you need to know. Distinguishing between statements and expressions will help us talk about the code we write.

- A **statement** is a line of code that performs an action. Python evaluates each statement in turn until it reaches the end of the file (remember oath 2?). `print(y * 7)` is a statement and so is `x = 14`. They each represent a full line of code and they each perform an action.
- An **expression** is any piece of code that reduces to one value. `y * 7` is an expression and so is `y * 7 + 14 - x` and `4 > 5`.

We will talk more about how expressions are handled by Python in the next section, but right now it is important that you understand that statements *do something* while expressions are things that reduces to a value. Hopefully, this distinction will be clearer when you have completed the following exercises.

Exercise 4-5

Did you notice in the above examples that `print(y * 7)` is a statement and `y * 7` is an expression? Yes, expressions can be part of statements. In fact they most often are. Similarly, expressions are often made up of other smaller expressions. E.g. `y * 7` is part of the larger expression `y * 7 + 14 - x`.

Take a look at this code:

```
x = 5
y = 20
z = (x + y) / 2 + 20
print(z * 2 + 1)
h = 2 * x - 9 * 48
print(h)
```

Write down the code on a piece of paper. Now mark all statements and all expressions. Remember that expression are often made up of smaller expressions, so you can find a *lot* of them. E.g. `(x + y)`, `2 + 20`, and `(x`

$+ y) / 2 + 20$ are all expressions. In fact, a single variable (like x) is also a small expression. Discuss with a fellow student. Do you agree on what find?

Exercise 4-6

Consider the following code:

```
greeting = 'Hello' + ' my '  
print(greeting + 'friend')
```

How many statements are there in this piece of code? How many expressions?

Substitution and Reduction

Although *substitution* and *reduction* may not sound like your new best friends, they truly are! If you remember to think about your Python code in terms of substitution and reduction, then programming will make a lot of sense. Understanding and using these simple rules you will allow to read and understand any code. If you do not, you may get by for a while - only to find yourself in big big trouble later when things start to become more complicated.

You should remember, from the section on variables in the previous chapter, that variables in Python are *either* assigned a value *or* substituted for the value they represent.

In the first two lines of code below, the variables x and y are each assigned a value. Now consider the last line in the example:

```
x = 4
y = 3
z = x * y + 8
```

Here x is *substituted* by the value 4 and y is *substituted* by the value 3. So now the expression after the equals sign reads $4 * 3 + 8$. Because we multiply before we add, $4 * 3$ *reduces* to 12 so that the expression now reads $12 + 8$. Finally, this *reduces* to the value 20. The very *last* thing that happens is that the variable z is assigned the value 20.

You should do these steps every time you see an expression. You may think that this is overdoing things a bit, but it is *not*. This kind of explicit thinking is what programming is all about and it will become increasingly important as the course progresses. So make sure you make it a habit while it still seems trivial. Then, over time, it will become second nature.

Now raise your right hand and read the third and last oath out loud:

“ **Oath 3:** I hereby solemnly swear to consciously consider every single substitution and reduction in every Python expression that I read or write from this moment on. ”

This was the last of the three oaths but it is *by far* the most important one. You can take your hand down now.

NB: You may not realize at this point, but the last two subsections are the most important ones in the book. Go back and read them many times as you proceed through the course. If you explicitly think in terms of substitution and reduction you will have no trouble. If you do not, you are entering a mine field with snowshoes on.

Exercise 4-7

Do the substitution and reduction steps with pen and paper, then run it to check yourself by inserting a print statement at the end.

```
x = 7
y = 4 + x
2 + x * x**2 + y - x
```

Exercise 4-8

Do the substitution and reduction steps with pen and paper, then run it to check yourself by inserting a print statement at the end.

```
a = 4
b = a
c = 2
c = a + b + c
```

Exercise 4-9

Do the substitution and reduction steps with pen and paper, then run it to check yourself by inserting a print statement at the end.

```
x = 1
x = x
```

Exercise 4-10

Do the substitution and reduction steps with pen and paper, then run it to check yourself by inserting a print statement at the end.

```
microsatellite = "GTC" * 41
```

Surprised?

Exercise 4-11

Do the substitution and reduction steps with pen and paper, then run it to check yourself by inserting a print statement at the end.

```
mini_gene = "ATG" + "GCG" + "TAA"
```

What did you do first here? Does the order of additions matter? What operations do Python perform first when operators have same precedence? (left to right, or right to left)

Exercise 4-12

Do the substitution and reduction steps with pen and paper, then run it to check yourself by inserting a print statement at the end.

```
number = 1 / 1 * 4
```

In what order are reductions made? Does the order of operations matter, and in what order does Python do the reductions?

Exercise 4-13

Do the substitution and reduction steps with pen and paper, then run it to check yourself by inserting a print statement at the end.

```
x = 4
y = x + x
```

Exercise 4-14

Do the substitution and reduction steps with pen and paper, then run it to check yourself by inserting a print statement at the end.

```
x = 4
x = x + 1
```

Exercise 4-15

Do the substitution and reduction steps with pen and paper, then run it to check yourself by inserting a print statement at the end.

```
x = 4
x += 1
```

Compare the final value of x to that in Section 4-14. Can you see what += is a short hand for? Nifty, right?

General exercises

The following exercises are meant to train your familiarity with the topics we have treated so far – in this case especially:

- Substitution
- Reduction
- Assignment
- Simple precedence rules
- Comparison operators
- Logical operators
- Distinction between text and numbers

Read each exercise and think hard about the questions before you code anything. *Then* write the code and try it out. Remember that it is crucial that you type it in – as super boring as it may be (remember oath one). This trains your accuracy and attention to detail and it builds programming into your brain. Play around with each bit of code. Make small changes and see how it behaves.

There is a reason why there are lots of questions in this exercise but no answers. You are supposed to find them yourself – also if it takes you quite a while. That is the way you build understanding. Some of the questions may seem trivial but do them anyway. If you only understand these concepts superficially they will come back and bite you in the ass when things get more complicated.

Exercise 4-16

Consider this code:

```
1.2 * 3 + 4 / 5.2
```


What does that expression evaluate to? Try to explicitly make all the reductions on a piece of paper before you write and run the code.

Exercise 4-17

Consider this code:

```
1.2 * (3 + 4) / 5.2
```

What does that expression evaluate to? Try to explicitly make all the reductions on a piece of paper before you write and run the code.

Exercise 4-18

Consider this code:

```
10 % 3 - 2
```

What does that expression evaluate to? Try to explicitly make all the reductions on a piece of paper before you write and run the code.

Exercise 4-19

Consider this code:

```
11 % (7 - 5)**2
```

What does that expression evaluate to? Try to explicitly make all the reductions on a piece of paper before you write and run the code.

Exercise 4-20

Consider this code:

```
a = 5
x = 9
banana = 7
x + 4 * a > banana
```

What does the last expression evaluate to? Try to explicitly make all the substitutions and reductions on a piece of paper before you write the code. What happens if you write and run the code? Why?

Exercise 4-21

Consider this code:

```
dance = 'can'
dance = dance + dance
print("Do the", dance)
```

What is printed? Try to explicitly make all the substitutions and reductions on a piece of paper before you write the code. What happens if you write and run the code? Why?

Exercise 4-22

Consider this code:

```
foo = 30
bar = 50
baz = bar + foo
```

```
print(baz)
bar = 10
print(baz)
```

There are two print statements. The first print statement prints 80. But what about the second print statement? Does that print 80 or 40? Find out and make sure you understand why it prints what it prints. If not, reread the section on substitution.

Exercise 4-23

Consider this code:

```
1 == '1'
```

and this:

```
1 == 1.0
```

What does this reduce to? Try to print it and see once you think you know. If you were wrong, make sure you figure out why.

Exercise 4-24

Consider this code:

```
a = '1'
b = '2'
c = a + b
print(a, b, c)
print(a + b == 3)
```

What is printed here? Write the code and see for yourself once you think you know. If you were wrong, make sure you understand why.

Exercise 4-25

Consider this code:

```
a = 1
b = 2
c = a + b
print(a, b, c)
print(a + b == 3)
```

What is printed here? Compare to Section 4-24. Write the code and see for yourself once you think you know. If you were wrong, make sure you understand why.

Exercise 4-26

Consider this code:

```
x = 4
print(x + 2 and 7)
print(x + 2 or 7)
x = -2
print(x + 2 and 7)
print(x + 2 or 7)
```

What is printed here? Write the code and see for yourself once you think you know. If you were wrong, make sure you understand why.

Exercise {#sec-puzzle) 4-27

In the code below I have shuffled the statements. Put them in the right order to make the code print 100.

```
x = x + 4
print(x)
x = x * 5
x = x * x
x = 4
```

Exercise 4-28

In the code below I have shuffled the statements. Put them in the right order to make the code print the string "Banana".

```
y = 'n'
x = 'B' + y + x
print(x)
x = 'a'
y = (x + y) * 2
```

Exercise 4-29

Make a puzzle exercise, like the two previous ones, for a fellow student.

Exercise 4-30

Remind yourself of the different types of Python values you know. E.g. one of them is integer (int). Make a list.

Exercise 4-31

You already know about several types of data values in Python. Two of them are integers called int, and decimal numbers (or floating points) called float. When you use an operator like + or > it produces a value. No matter what you put on either side of > in it produces a boolean value (bool), True or False. For other operators the type of value produced depends on which values the operator works on. Try this and see if you print an integer or a float (8 or 8.0):

```
x = 4
y = 2
result = x * y
print(result)
```

Now try to replace 4 with 4.0. What type is result now?. Try to also replace 2 with 2.0. What type is result now? Can you extract a rule for what the * operator produces depending on the what types the two values have?

Exercise 4-32

In Section 4-31 you investigated what types of values the * operator produce. Redo that exercise with the operators: +, -, /, **, //, and %. What are the rules for what is returned if both values are integers, one value is a float, or both values are floats?

Exercise 4-33

Make a list of all the operators you know so far in order of precedence (without looking in the notes). Then check yourself.

Exercise 4-34

What does his expression reduce to and what type of value is it?

```
3 > 2
```

Exercise 4-35

What does his expression reduce to and what type of value is it? Do all the reduction steps in your head.

```
2 - 4 * 5 - 2 * 1/3
```

Exercise 4-36

What does his expression reduce to and what type of value is it? Do all the reduction steps in your head.

```
3 > 2 and 2 - 4 * 5 - 2 * 9
```

Exercise 4-37

What is printed here and why?:

```
print(True and "banana" or "orange")
```

Try to change the True value to False and see what happens. Can you explain it? If not look at Section 3-14 again.

Exercise 4-38

What does his expression reduce to? Do all the reduction steps in your head.

```
0 and 1 or 2
```

Exercise 4-39

What does his expression reduce to? Do all the reduction steps in your head.

```
4 and 1 or 2
```

Exercise 4-40

If you understood Section 4-37, then you should also understand this one:

```
weather = 'rain'
what_to_do = weather == 'rain' and 'watch movies' or 'go swimming'
print(what_to_do)
```

What happens if you change 'rain' in the first line to something else (like 'sun')?

Exercise 4-41

What is the value of `result` once the code below has run? Do the substitutions, reductions, and assignments in your head before you run the code.

```
x = 7
y = 13
z = x + y
x = 0
result = x + y + z
```

Exercise 4-42

What is the value of `result` once the code below has run? Do the substitutions, reductions, and assignments in your head before you run the code.

```
x = 5
y = x + 1
x = y + 1
y = x + 1
result = x + y
```

Exercise 4-43

In the code below I have shuffled the statements. Put them in the right order to make the code print 9. To do that you must think about which values each variable will in each statement depending on the how you order the statements.

```
x = x + 1
y = 5
y = y - 1
print(y)
x = 1
y = y * x
```

Exercise 4-44

In the code below I have shuffled the statements. Put them in the right order to make the code print 'Mogens'

```
c = b
print(c)
a = b + a
b = 'og'
b = c + a
c = 'M'
a = 'ens'
```

Exercise 4-45

Make three exercises that requires the knowledge of programming so far. Have your fellow students solve them.

5 Course tools

Wax on, wax off

“ Mr. Miyagi: First, wash all car. Then wax. Wax on. . .

Daniel: Hey, why do I have to. . . ?

Mr. Miyagi: Ah ah! Remember deal! No questions!

Daniel: Yeah, but. . .

Mr. Miyagi: Hai! Wax on, right hand. Wax off, left hand.
Wax on, wax off. Breathe in through nose, out of mouth.
Wax on, wax off. Don't forget to breathe, very important.
[walks away, still making circular motions with hands] Wax
on. . . wax off. Wax on. . . wax off.

”

Seeing the sequence of substitutions and reductions in a Python expression will become natural over time. Until it does, you are in troubled waters, and if you do not practice in time, you may only realize this too late. Considering how simple this is to practice and how crucial it is to your progress, I have written a small companion program called `myiagi` where you can train this particular skill daily. The program is installed in the conda environment you created for this source, so make sure it is activated as described. To run the program, you execute this command in the terminal:

myiagi

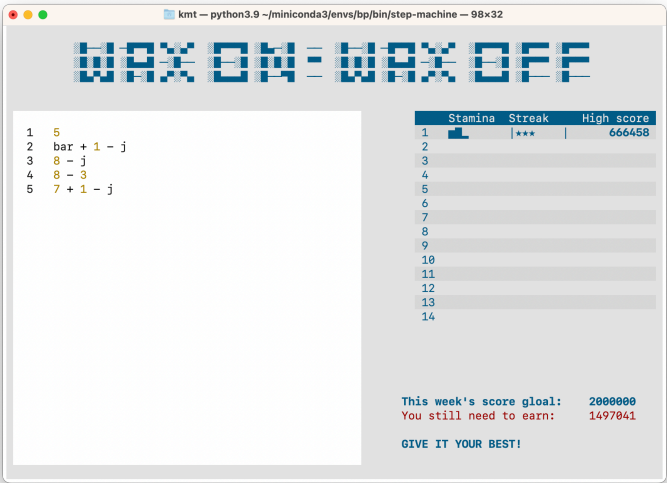


Figure 5.1: Visual Studio Code (VScode)

It should look like Figure 5.1, and the simple game is as follows. The program generates a Python expression. From that expression, it then performs all the substitution and reduction steps. Each substitution or reduction results in an intermediate expression until only a single Python value remains. Here is an example where the expression is $4 * y + x$ and the value it reduces to is 37:

1. $4 * y + x$
2. $4 * 8 + x$
3. $24 + x$
4. $24 + 13$
5. 37

You do not know what values the `y` and `x` variables point to, but you can deduce it from the sequence of expressions that they are 24 and 13. In the game, you are given a series of numbered expressions in the wrong order like this:

```
1.  4 * y + x
2.  37
3.  4 * 8 + x
4.  24 + x
5.  24 + 13
```

Your task is to put them in the right order so that the original expression is at the top and the single Python value it reduces to is at the bottom. Now, you might grab line 2 by tabbing 2 on your keyboard (the number turns red so you can see it is active). Then, you move the line using the up/down arrow keys. If you move it to the bottom, the list then looks like this:

```
1.  4 * y + x
2.  4 * 8 + x
3.  24 + x
4.  24 + 13
5.  37
```

Now, you repeat this process until the order is correct (the program will let you know when it is). The fewer lines you grab to produce the right order, the more points you earn. Problems with longer lists of expressions also earn you more points. As problems become harder and include more aspects of Python, solving them also awards more points. Each week has a score goal to guide your effort. Reaching this goal ensures that you practice as much as you should. Practicing a bit every day daily is more effective than practicing a lot a few days a week. To provide an incentive, the points you earn slowly expire, so the easiest way to maintain your score is to practice a bit every day.

A helping hand

Using the `myiagi`, you train your ability to read and understand Python expressions. Seeing a similar breakdown of a Python expression in your code may also be helpful. For that purpose, I have written another tool called `print-steps`. Say you have some code like the one below and need clarification on how the single value assigned to `z` is produced (here, you are probably not).

```
x = 7
y = 5
z = x * y + 4
```

All you need to do is then to add `# PRINT STEPS` comment to the end of the line like this:

```
x = 7
y = 5
z = x * y + 4 # PRINT STEPS
```

Say your file is called `myfile.py`, you would normally run the code like this:

```
python myfile.py
```

But to see the breakdown of expressions marked by `# PRINT STEPS`, you need to run your code with the `print-steps` program instead:

```
print-steps myfile.py
```

The command prints the following in the terminal:

```
Line 4 in test_studentfile.py:  
As written:      z = x * y + 4  
Substitution:    z = 7 * y + 4  
Substitution:    z = 7 * 5 + 4  
Reduction:       z = 35 + 4  
Reduction:       z = 39
```

You can even mark more than one line like this and have print-steps break down all of them for you:

```
x = 7  
y = 5  
z = x * y + 4 # PRINT STEPS  
k = z * 42 # PRINT STEPS
```

like this:

```
Line 3 in myfile.py:  
As written:      z = x * y + 4  
Substitution:    z = 7 * y + 4  
Substitution:    z = 7 * 5 + 4  
Reduction:       z = 35 + 4  
Reduction:       z = 39  
  
Line 4 in myfile.py:  
As written:      k = z * 42  
Substitution:    k = 39 * 42  
Reduction:       k = 1638
```

However, it would be best if you used this helping hand sparingly. It is much better to train your ability to do this in your head with the help of Mr. Myagi. Trust me, it works.

6 Controlling behavior

This chapter is about how you make your program do different things under different circumstances. Making functionality dependent on data is what makes programs useful.

If-statement

The small programs you have written so far all run the exact same sequence of statements (lines). Imagine if you could control which statements were run depending on the circumstances. Then you would be able to write more flexible and useful programs. Cue the music - and let me introduce: the “if-statement”.

Write the following carefully into a file. It is a small program to monitor bus passenger status. Notice the colon ending the if-statements. Also, note that the lines below each if-statement are indented with exactly four spaces. While you write the program, try to figure out what the if-statement does. Then run the code and see what happens.

```
bus_seats = 32
passengers = 20
bags = 20

print(passengers, "people ride the bus")
```

```
if bus_seats >= passengers + bags:
    print("Smiles, everyone has room for bags")

if bus_seats >= passengers:
    print('Everyone gets to sit down, no complaints')

if bus_seats < passengers:
    print('Some passengers standing, annoyed')

if bus_seats < passengers / 3:
    print("General dissatisfaction, some swearing too")
```

Try to change the values of `bus_seats`, `passengers` and `bags` and see how execution of the program changes.

You have probably realized that the if-statements control which print-statements that are evaluated. A statement nested under an if-statement is only evaluated if the expression between the if keyword and the `:` reduces to a value Python considers as *true*. This does not happen if the expression between the if and `:` reduces to a value Python considers *false*.

Remind yourself that when asked to evaluate something as true or false, Python will interpret zero and empty values (like `0` and `' '`) as False and all other non-zero and non-empty values as True.

Exercise 6-1

Which of the following letters are printed: A, B, C, D, E, F, G. Make up your mind before you write and run the code.

```
if 0:
    print('A')

if "Banana":
    print('B')

if 3.14159265359:
    print('C')

if False:
    print('D')

if 9 > 5 and 4 < 7:
    print('E')

if '':
    print('F')

if False or "banana":
    print('G')
```

Exercise 6-2

What happens if you forget to write the `:` in the if-statement?

```
if 4 > 2
    print('Hi!')
```

Exercise 6-3

What happens if you do not indent the code under the if-statement?

```
if 4 > 2:  
print('Hi!')
```

“ By now you have probably know that your text editor is intelligent when it comes to indentation. If you hit Enter after a statement ending with :, it will indent the next line with four spaces. Also, if you use the tab in python code, it will produce four spaces for you. ”

FAQ

Q: Isn't "If" a poem by Rudyard Kipling?

A: Yes.

Else-statement

Sometimes you not only want your program to do something if an expression reduces to True, you also want it to do something *else* if it is False. It is as simple as it looks:

```
cookies = 3  
  
if cookies > 0:  
    print("Uh, I wonder if we have some milk too...")  
else:
```

```
print("Sigh!")
```

Remember to put a `:` after the `else` keyword. Write the code and change the value of `cookies` to `0`.

Exercise 6-4

Test your understanding about which expressions that reduce to a `True` or `False` value. Write the code below and then see how it responds to different values of `x`. Try to come up with other variations yourself.

```
x = 0.0
# x = '0'
# x = ' '
# x = ''
# x = not 0
# x = 'zero'

if x:
    print('x is substituted with True in the if-statement')
else:
    print('x is substituted with False in the if-statement')
```

FAQ

Q: Isn't "Else" a poem by Rudyard Kipling?

A: No.

Exercise 6-5

What do you think this code prints? Notice how you can nest if and else-statements under other if and else-statements. This way you can make your program only include some statements when certain combinations of conditions are met. Just remember that the code below each if or else is indented by four spaces. Try to change the True/False values of milk and cookies.

```
milk = False
cookies = True
if milk:
    if cookies:
        status = 'Good times!'
    else:
        status = 'Not thirsty, thanks or asking'
else:
    if cookies:
        status = 'How does something like this happen?'
    else:
        status = 'Whatever...'

print(status)
```

Blocks of code

In the examples above, some lines are indented more than others, and you probably already have some idea of how this is interpreted by Python. Indentation defines blocks of code. Whether each block of code is evaluated when your code runs, is controlled by the if and else statements. The following three rules define individual blocks of code:

1. All statements in a block of code have the *same indentation*. That is, they line up vertically.
2. A block of code *begins* at the first line of code at a line that is indented more than the one before it.
3. A block *ends* when it is followed by a line that is less indented, or at the last line of code.

This way, a block can be nested inside another block by indenting it further to the right as shown in Figure 6.1. Compare the example in Figure 6.1 to the code example above. Note how a colon at the end of a statement means “this applies the block of code below”. Make sure you understand which print statements that are controlled by which if and else statements.

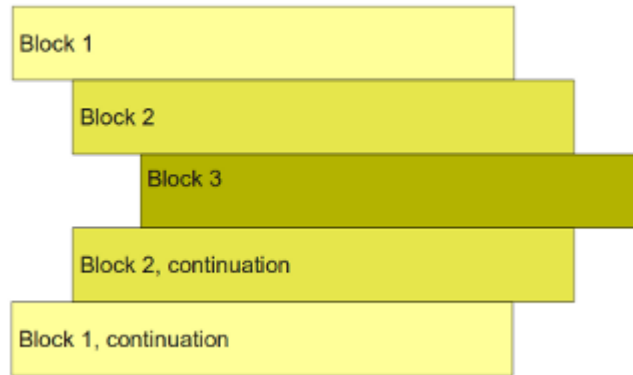


Figure 6.1: The amount of indentation defines blocks of code

Elif-statement

Say you need to test a number of mutually exclusive scenarios. E.g. if a base is equal to A, T, C or G. You can do that like in the example below, but it is very verbose and shifts your code further and further to the right.

```
base = 'G'

if base == 'A':
    print('This is adenine')
else:
    if base == 'T':
        print('This is thymine')
    else:
        if base == 'C':
            print('This is cytosine')
        else:
            print('This is guanine')
```

This is where an elif statement can be helpful. It is basically short for “else if”. If you compare to the example below the correspondence is hopefully obvious.

```
base = 'G'

if base == 'A':
    print('This is adenine')
elif base == 'T':
    print('This is thymine')
elif base == 'C':
    print('This is cytosine')
else:
    print('This is guanine')
```

Here we put an else-statement at the end to capture all cases not covered by the if-statement and the two elif-statements.

Exercise 6-6

You can use logical operators (and, or, not) in the expressions tested in an if-statement. Can you change the program from Section 6-5 so that there are no nested if-statements - in a way so the program still does exactly the same? You can use if, elif and else and test if e.g. both milk and cookies are true using and.

Exercise 6-7

In the snippet of code below there are three blocks with three statements in each. Which statements belong to which block? Which statements are executed?

```
x = 5
if x > 4:
    y = 3
    if x < 1:
        x = 2
        y = 7
        z = 1
    x = 1
z = 4
```

Exercise 6-8

Can you see four blocks of code? If not, read the three rules above again. Which statements are executed?

```
x = 5
if x > 4:
```

```
y = 3
if x < 1:
    x = 2
    y = 7
else:
    x = 1
    y = 9
z = 4
```

General exercises

Exercise 6-9

Will this print You are a super star!?

```
if -4 and 0 or 'banana' and not False:
    print("You are a super star!")
```

Exercise 6-10

Will this print You are a super star!?

```
if -1 + 16 % 5 == 0 :
    print("You are a super star!")
```

Exercise 6-11

Assign values to two variables `x` and `y`. Then write some code that prints OK if and only if `x` is smaller than five *and* `y` is larger than five. Do it using *two* if statements:

```
x = 3 # or something else
y = 7 # or something else

# rest of code here...
```

Now solve the same problem using only *one* if statement.

Exercise 6-12

Assign values to two variables `x` and `y`. Then write some code that prints OK if and only if `x` is smaller than five *or* `y` is larger than five. Do it using *two* if statements:

```
x = 3 # or something else
7 = 7 # or something else

# rest of code here...
```

Now solve the same problem using only *one* if statement and *one* elif statement.

Exercise 6-13

Assign values to two variables `x` and `y`. Then write some code that prints OK if either `x` or `y` is zero, but not if both are zero (this is tricky one).

```
x = 3 # or something else
y = 7 # or something else

# rest of code here...
```

Exercise 6-14

Which value of x makes the code below print Banana?

```
x =
s = ''
if x**2 == 16:
    s = s + 'Ba'
if x + 6 == 2:
    s = s + 'na'
if 7 == x - 3:
    s = 'na' * 2
else:
    s = s + 'na'
print(s)
```

Exercise 6-15

Make three exercises that requires the knowledge of programming so far. Have your fellow students solve them.

7 Organising your code

This chapter is about how you can organize your code into chunks that you can call upon to perform a well defined tasks in your program.

Functions

Buckle down for the most powerful and useful thing in programming. Functions! Functions serve as mini-programs that perform small well-defined tasks in your program.

I have started to write a song about functions:

```
print("Functions are super, Functions are cool")
print("When writing a program they are a great tool")
print("La la dim du da da di")
print("Skubi dubi dumdi di")
print("Bing di dubi dum da di")

print("Functions are used to package some code")
print("They are not so strange that your head will explode")
print("La la dim du da da di")
print("Skubi dubi dumdi di")
print("Bing di dubi dum da di")
```

I am going to add a lot more verses and I do not want to have to write the entire chorus every time. So what would be more natural than to make

a function named `chorus` that takes care of that for us? That way we can write our song the way lyrics with a chorus are usually written:

```
def chorus():
    line1 = "La la dim du da da di"
    line2 = "Skubi dubi dumdi di"
    line3 = "Bing di dubi dum da di"
    return line1 + '\n' + line2 + '\n' + line3

print("Functions are super, Functions are cool")
print("When writing a program they are a great tool")
print( chorus() )

print("Functions are useful to wrap up some code")
print("They are not so strange that your head will explode")
print( chorus() )
```

First, let us break down the function definition in the top part of this code:

1. We *define* a function with the `def` keyword (which is short for “define” in case you wonder).
2. After `def` we write the name of the function. We call the function `chorus`. We could name it something else, but like good variable names, good function names can help you remember what your code does.
3. After the name you put two parentheses, `()`.
4. Then a colon, `:`.
5. The statements that are part of the function are nested under the `def` statement and are indented with four spaces exactly like we do under `if`-statements.
6. The `return`-statement ends the function. The expression after the `return` keyword reduces to a *value* that the function then returns.

When Python runs this code, each line is executed one by one starting from the first line (remember oath two?). So in this case python first executes the *definition* of the chorus function. The only thing that has happened after Python has executed the first five lines of code is that it has assigned the name chorus to the four indented statements. So Python now “knows” about the chorus function (like it “knows” about a variable x after we do `x = 4`).

To *use* the function, we “call” it by writing its name followed by parentheses: `chorus()`. When it comes to functions, “use”, “call” and “run” means the same thing. As you can see, we call the function twice in the rest of the code. Each time we do, the following happens:

1. When a function is *called*, each statement in the definition is executed one after the other. If you look at the function definition, you can see that our chorus function has four statements.
2. The first statement assigns a string value to the variable `line1`.
3. The second statement assigns a string value to the variable `line2`.
4. The third statement assigns a string value to the variable `line3`.
5. The fourth statement is a return-statement. The expression after the return keyword in the final statement reduces to a *value* and this value is what the function call is substituted for. In this case, that value is the following string:

```
"La la dim du da da di\nSkubi dubi dumdi di\nBing di dubi dum da di"
```

So the key properties of functions are:

- A function names a piece of code (some statements) just like variables name values like strings and numbers.
- We call a function by writing the function name followed by parentheses: `chorus()`. Just writing the function name will not call the function.

- When a function is *called* it is substituted by the *value* that the function *returns* – exactly like a variable in an expression is substituted by its value. It is absolutely crucial that you remember this.

Exercise 7-1

Now that we have a chorus function, that part is out of the way and we can concentrate on our song without having to worry about remembering how many “la la”s it has and so on. Try to change the “lyrics” in the chorus a little bit. Notice how you only need to make the change in one place to change all the choruses in the song – cool right? Without the function, you would have to rely on correctly changing the code in many different places.

Exercise 7-2

Try to delete the return-statement in the chorus function (the last line in the function) and run the code again. You should see something like this:

```
Functions are super, Functions are cool
When writing a program they are a great tool
None
Functions are used to wrap up some code
They are not so strange that your head will explode
None
```

It seems that the function call (`chorus()`) is now substituted with `None`. How can that be when we did not return anything? The reason is that when you do not specify a return statement the function returns `None` by default. This is to honour the rule that variables and a function calls are

substituted by a value, and None is simply the value that Python uses to represent “nothing”. None is basically a value denoting the lack of value. As you just saw it is used to represent that no value is returned from a function. It can also be assigned to a variable as a placeholder value until another value is assigned:

```
x = None
x = 4
```

Also, None is considered false in a logical context:

```
print(not None)
```

Exercise 7-3

Try this variant to the chorus function. Go through the code *slowly* and repeat all the steps in the breakdown of what happens when a function is called. Remember to also do each substitution and reduction carefully.

```
def chorus():
    line1 = 'La la'
    line2 = 'Du bi du'
    return line1 + '\n' + line2
```

Do the same for this variant:

```
def chorus():
    line1 = 'La la'
    line2 = 'Du bi du'
    chorus_text = line1 + '\n' + line2
    return chorus_text
```

and for this variant:

```
def chorus():  
    return "La la\nDu bi du"
```

Exercise 7-4

What do you think happens if you move the definition of `chorus` to the bottom of your file? Decide what you think will happen and why (maybe you remember what happens when you try to use a variable in an expression before you have defined it?). Then try it out.

```
print("Functions are super, Functions are cool")  
print("When writing a program they are a great tool")  
print( chorus() )  
  
print("Functions are useful to wrap up some code")  
print("They are not so strange that your head will explode")  
print( chorus() )  
  
def chorus():  
    line1 = "La la dim du da da di"  
    line2 = "Skubi dubi dumdi di"  
    line3 = "Bing di dubi dum da di"  
    return line1 + '\n' + line2 + '\n' + line3
```

Make sure you understand how the error you get relates to the way Python runs your script (remember oath two?). If you still do not understand, do the next exercise and then return to this one.

Exercise 7-5

Which error do you get here and why? How is that similar to the error in the previous exercise?

```
print(x)
x = 7
```

Exercise 7-6

Consider the code below. Do all the substitution and reduction steps in your head. Remember that each function call is substituted by the value that the function returns. Then run it.

```
def lucky_number():
    return 7

x = lucky_number()
y = lucky_number()
twice_as_lucky = x + y
print(twice_as_lucky)
```

Now change the code to that below. The code makes the same computation but in fewer steps. Do all the substitution and reduction steps again.

```
def lucky_number():
    return 7

twice_as_lucky = lucky_number() + lucky_number()
print(twice_as_lucky)
```

Now change the code to that below. The code makes the same computation but in fewer steps. Do all the substitution and reduction steps again.

```
def lucky_number():  
    return 7  
  
print(lucky_number() + lucky_number())
```

Functions can take arguments

The functions we have written so far are not very flexible because they return the same thing every time they are called. Now write and run this beauty:

```
def square(number):  
    squared_number = number**2  
    return squared_number  
  
result = square(3)  
print(result)
```

Notice how we put a variable (`number`) between parentheses in the function *definition*. This variable is assigned the value that we put between the parentheses (`3`) when we *call* the function. So when we call the function like this: `square(3)` – then this implicitly happens inside the function: `number = 3`.

Here is another example:

```
def divide(numerator, denominator):  
    result = numerator / denominator  
    return result  
  
division_result = divide(44, 77)  
print(division_result)
```

When the function call `divide(44, 77)`, these two things implicitly happen: `numerator = 44` and `denominator = 77`.

Take note of the following three important points: 1. The *values* that we pass to the function in the function call (like 3, 44 and 77) are called *arguments*. It is crucial to remember that it is *values* and not variables that are passed to functions. 2. The *variables* in the definition line of a function, like `number`, `numerator` and `denominator`, are called *parameters*. They hold the *values* passed to the function when it is called (the arguments). 3. You can define functions with any number of *parameters* as long as you use the same number of *arguments* when you call the function.

Exercise 7-7

Try to call your `divide` function like this `divide(77, 44)`. What does it return and what do you learn from that? Does the order of arguments and parameters correspond?

Exercise 7-8

Try to call your `divide` function like this `divide(44)`. Do you get an error, and what do you learn from that?

Exercise 7-9

Try to call your divide function like this `divide(44, 77, 33)`. Do you get a different error message, and what do you learn from that?

Exercise 7-10

Read this code and do all substitution and reduction steps from beginning to end.

```
def square(x):  
    return x ** 2  
  
result = square(9) + square(5)  
print("The result is:", result)
```

Now replace the line `return x ** 2` with `print(x ** 2)`. What is printed now? and why?

Exercise 7-11

As described above, a return statement ends the function by producing the value that replaces the function call. If a function has more than one return statement, then the function ends when the first one is executed.

```
def assess_number(x):  
    if x < 3:  
        return 'quite a few'  
    if x < 100:  
        return 'a lot'  
    return 'a whole lot'
```

```
nr_apples = 2
print(nr_apples, "apples is", assess_number(nr_apples))
```

What happens when x is 2, 3, 50, 200? Think about it first.

Functions and variables

A function call is temporary little world only exists from the function is *called* and until it *returns* its value. It did not exist *before* the function was called and it does not exist *after* the function returns its value. By necessity, the variables defined in your function are also temporary.

This means that variables defined inside a function are private to each function call. It also means that variables defined inside functions are not available to code *outside* the function. Running the following example in should help you understand this:

```
def make_greeting():
    greeting = 'Guten tag'
    name = 'Heinz'
    message = greeting + " " + name
    return message

greeting = 'Buongiorno'
name = 'Giovanni'
print( make_greeting() )
print(greeting + " " + name)
```

Notice how Heinz and Giovanni are greeted in their native languages. This means that the variable definitions inside the function does not overwrite the Italian versions already defined outside the function. This is

because the variables defined in the function are temporary and private to the function, even if they have the same names as variables outside the function. This is why the function call `make_greeting()` in the print statement does not change the values of the variables that are printed in the last line.

Now try to “comment out” the line `greeting = 'Guten tag'` and run the example again. All of a sudden Heinz is greeted in Italian! The reason is that now Python cannot find a definition of `greeting` inside the function. It then looks outside the function for a definition and finds the Italian version.

Now try to “comment out” the line `greeting = 'Buongiorno'` and run the example again. You get an error, but which one? Python complains that it cannot find a definition of `greeting`. The reason is that once the last print statement is executed the small world of the function call in the previous line no longer exists.

You should learn two rules from the above example:

1. All variables that you define inside a function are *private* to the function. If a variable in a function has the same name as a variable in the main script (like `greeting` above) then these are two *separate* variables that just happen to have the same name.
2. When you use a variable like `greeting` in the function (E.g. `message = greeting + " " + name`), then Python checks if the variables have been defined in the function. If that is not the case, then it will look for it outside the function. In the above example, it finds `name` in the function and `greeting` outside the function. It is good practice to make your functions “self-contained”, in the sense that Python should not have to look outside the function for variables.

Exercise 7-12

Try this version of the example above. Now `name` is defined as a function parameter, but is it still a function variable just like `greeting`.

```
def make_greeting(name):
    greeting = "Guten tag"
    message = greeting + " " + name
    return message

greeting = 'Buongiorno'
name = 'Giovanni'
print( make_greeting("Heinz") )
print(greeting + " " + name)
```

Exercise 7-13

Consider the following example:

```
def double(z):
    return z * 2

x = 7
result = double(x)
print(result)
```

When the function is called (`double(x)`) the `x` is substituted by its value 7. That *value* is passed as the argument and assigned to the function parameter `z` (`z = 7`). `z` is a private function variable and does not exist before or after the function call. Does this change in any way if we use the variable name `x` instead of `z` like below?

```
def double(x):  
    return x * 2  
  
x = 7  
result = double(x)  
print(result)
```

Do *all* substitutions and reductions for each line of code from top to bottom. Keep the sequence of events in mind and remember that a function definition is merely a template describing a mini-world that is created anew everytime the function is called.

Builtin functions

So far we have only talked about functions you write yourself, but Python also has built-in functions that are already available to you. They work just like a function you would write yourself. You already know the `print` function quite well, and that is an example of a function that prints something but returns `None`. There are many other useful builtin function, but for now, I will just tell you about another two: Those are `len` and `type`.

Exercise 7-14

Try these examples:

```
x = 'Banana'  
print("The value of variable x is of type", type(x))  
print("The value of variable x has length", len(x))
```

As you can see, `type` returns the type of the value passed as the argument, and `len` returns the length of the value passed as the argument. The `type` function is handy in case you wonder what type a value has, but it is not a function we will use in this course. The `len` function, however, is your new best friend. You will see why soon enough.

Exercise 7-15

Try to change the value of the `x` in Section 7-14 to an integer or a float and see what happens when you run it. Do you get an error? Does it make sense that not all types of values can meaningfully be said to have a length?

Exercise 7-16

What happens if you pass an empty string (`""`) as the argument to the `len` function?

Exercise 7-17

What is printed here? Think about it first and then try it out. Remember to do the substitution and reduction steps.

```
return_value = print("Hello world")
print(return_value)
```

Exercise 7-18

What is printed here? Think about it first and then try it out. Remember to do the substitution and reduction steps.

```
print(print("Hello world"))
```

General exercises

The following exercises treat the areas we have worked on in this and previous chapters. They are meant to train your familiarity with if-statements and functions. Remember that the purpose of the exercises is not to answer the questions but to train the chain of thought that *allows* you to answer them. Play around with the code for each example and see what happens if you change it a bit.

Exercise 7-19

Consider this function definition that takes a single number as the argument:

```
def square(n):  
    return n**2
```

What does it do? What does it return? What number does `square(2)` then represent?

Below I have used it in some expressions that are printed. Make sure you understand what each expression evaluates to. Do the explicit substitutions and reductions on paper before you run it. Remember that we

substitute a function call (like `square(2)`) for the value it returns, just like we substitute a variable `x` for the value it points to.

```
print(square(3))
print(square(2 + 1))
print(square(2) * 2 + square(3))
print(square(square(2)))
print(square(2 * square(1) + 2))
```

Exercise 7-20

What does this function do? How many parameters does it have? How many statements does the function have? What does the function print? Which value does it return?

```
def power(a, b):
    print("This function computes {}**{}".format(a, b))
    return a**b

print(power(4, 2))
```

Try (possibly strange) variations of the code like the ones below to better understand the contribution of each line of code. What is the difference between `return` and `print`? What happens when the Python gets to a `return` statement in a function? What happens when the function does not have a `return` statement?

Variation 1:

```
def power(a, b):
    print("This computes", a, "to the power of", b)
    print(a**b)
```

```
result = power(4, 2)
print(result)
```

Variation 2:

```
def power(a, b):
    print("This computes", a, "to the power of", b)
    return a**b

result = power(4, 2)
print(result)
```

Variation 3:

```
def power(a, b):
    print("This computes", a, "to the power of", b)
    a**b

print(power(4, 2))
```

Variation 4:

```
def power(a, b):
    return a**b
    print("This computes", a, "to the power of", b)

print(power(4, 2))
```

Exercise 7-21

Define a function called `diff`, with two parameters, `x` and `y`. The function must return the difference between the values of `x` and `y`.

```
Example:
def diff(x, y):
    ...

diff(8, 2) # should return 6
diff(-1, 2) # should return -3
```

Save the value returned from the function in a variable. Then test if the function works correctly by comparing the result to what you know is the true difference (using `==`).

Exercise 7-22

Define a function called `all_equal` that takes five arguments and returns `True` if all five arguments have the same value and `False` otherwise. The function should work with any input, for example:

```
all_equal("Can", "Can", "Can", "Can", "Can")
all_equal(0, 0, 0, 0, 0)
all_equal(0.5, 0.5, 0.5, 0.5, 0.5)
all_equal(True, True, True, True, True)
```

Hint: You test equality with `a == b`. Now think back to what you learned about logic. Which operator can you use to test if `a == b` *and* `b == c`?

Exercise 7-23

Define a function called `is_even` which takes one argument and returns True if (and only if) this is an even number and False otherwise (remember the modulo operator?).

```
is_even(8) # should return True
is_even(3) # should return False
```

Exercise 7-24

Define a function called `is_odd` which takes one argument and returns True if (and only if) the argument is an odd number and False otherwise.

```
is_odd(8) # should return False
is_odd(3) # should return True
```

Can you use the `is_even` you defined in Section 7-23 to complete this exercise? How? Why is that a good idea?

Exercise 7-25

Here is a function that should return True if given an uppercase (English) vowel, and False otherwise:

```
def is_uppercase_vowel(c):
    c == 'A' or c == 'E' or c == 'I' or c == 'O' or c == 'U'

char = 'A'
if is_uppercase_vowel(char):
```



```
    print(char, "is an uppercase vowel")
else:
    print(char, "is NOT an uppercase vowel")
```

Now type the code exactly as shown and run it. Do you get what you expect? Does the code work? If not, try to figure out why. Try print the value that the function returns. Does that give you any hints about the cause of the problem?

Exercise 7-26

Define a function called `is_nucleotide_symbol` which takes one argument and returns True if this is either A, C, G, T, a, c, g or t, and False in any other case.

Name your parameter something sensible like `symbol`.

```
is_nucleotide_symbol("A") # should return True
is_nucleotide_symbol("B") # should return False
is_nucleotide_symbol("Mogens") # should return False
is_nucleotide_symbol("") # should return False
```

Exercise 7-27

Define a function called `is_base_pair` which takes two parameters, `base1`, `base2`, and returns True if `base2` is the complementary of `base1`, and False otherwise.

```
is_base_pair("A", "G") # should return False
is_base_pair("A", "T") # should return True
is_base_pair("T", "A") # should return True
```

```
is_base_pair("Preben", "A") # should return False
```

Exercise 7-28

Did you find the bug in Section 7-25? You were supposed to find that the function did not have a return value. This makes the function return `None` by default. Do you think the `None` value is considered true or false in an if-statement?

Exercise 7-29

Define a function called `celcius2fahrenheit` that converts from celsius to Fahrenheit. You can do this because you know the linear relationship between the two. On Figure 7.1 you can see that the slope is $9 / 5$ and the intercept is 32. The function should have one parameter `celsius`. Inside the function, you should define the variables `slope` and `intercept` and give them the appropriate values. Then you can calculate the conversion to Celcius using these variables and return the result.

Exercise 7-30

Try to change your conversion function so it takes three arguments, corresponding to `celsius`, `slope` and `intercept` so you can call it like this to convert 27 degrees celsius: `conversion(37, 9 / 5, 32)`. Now you have a function that can do any linear conversion that you can put inside another function like this:

```
def celcius2fahrenheit(celsius):  
    return conversion(celsius, 9 / 5, 32)
```

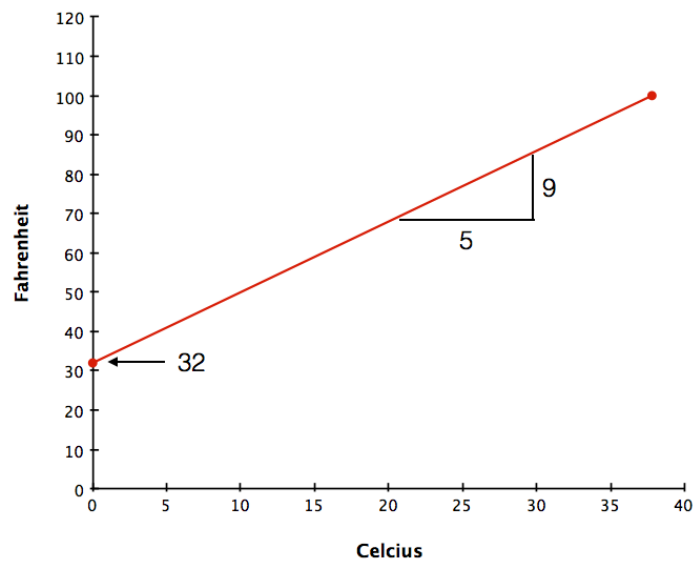


Figure 7.1: Temperature conversion

Exercise 7-31

Now try to extend this to a different problem: It has been found that the height and weight of a person are related by a linear equation with slope = 0.55 and intercept = -25. Define a function called `predict_weight` which takes just one argument, the height of a person, and returns the estimated weight of the person.

Exercise 7-32

By now you know that some of the words in your code have specific purposes. `def` defines functions, `return` returns value from a function, and `is` is a logical operator etc. Here is a list of the ones you will see in this course: `and`, `assert`, `break`, `continue`, `def`, `del`, `elif`, `else`, `False`, `for`, `from`, `if`, `import`, `in`, `is`, `not`, `or`, `pass`, `return`, `while`, `True`, `None` (you can see a full list [here](#))

These words are reserved for their special purposes in Python and you will not be allowed to assign values to them. Try this to see for yourself:

```
None = 4
```

or this:

```
and = 2
```

FAQ - Frequently Asked Questions

Q: Can function names be anything?

A: Just about. The rules that apply to variable names also apply to function names. Good function names are lower case with underscores (`_`) to separate words, like in the examples above.

8 Python values are objects

This chapter introduces the notion of an object, one of the most central aspects of Python. Once you get catch your breath, you will love that all Python values are objects.

Methods

In Python, a value like an integer or string, not only holds data. It is also packaged with a lot of useful functionality relevant to the particular *type* of value. When a value is packaged with such relevant functionality and meta information, programmers call it an *object* - and in Python *all* values are objects.

The associated functionality comes in the form of *methods*. You can think of methods as functions that are packaged together with the value. For example, string values have a method called `capitalize`. Try it out:

```
x = "banana".capitalize()
print(x)
```

To call the method on the string value, you connect the string value and the method call with a dot. So to call a method on a value you do the following:

1. Write the value (or a variable name that substitutes for a value).
2. Then write a ..

3. Then write the name of the method (like `capitalize`).
4. Then write two parentheses to call the method. If the method takes any arguments other than the value it belongs to, then you write those additional values between the parentheses with commas in between, just as when you call a function.

You can see that the method call looks just like a function call and in many ways calling a method works much like calling a function. The difference is that when we call a function we say: *“Hey function, capitalize this string!”*. When we call a method we say: *“Hey string, capitalize yourself!”*

So why do we need methods? Why do we need them when we have functions? It turns out that it is very handy to have some relevant and ready-to-use functionality packaged together with the data it works on. You will start to appreciate that sooner than you think.

Methods are almost always used with variables. So remember to do any substitutions and reductions required. When we put a method call after a *variable* like below, the variable is first substituted for its value and *then* the method is called on the value. Consider the second line of this example:

```
x = "banana"
print(x.capitalize())
```

Here `x` is first substituted by `"banana"` and *then* the method is called on that value, like this: `"banana".capitalize()`.

Now write and run these examples:

```
message = "Methods Are Cool"
print(message)
```

```
shout = message.upper()
print(shout)

whisper = message.lower()
print(whisper)

new_message = message.replace("Cool", "Fantastic")
print(new_message)
```

You can see what these methods do. For example: `upper` returns an uppercased copy of the string.

Exercise 8-1

Write and run the following code. What do you think it does?

```
line = '\n\tSome text\n'
print(">{}<".format(line))

line = line.strip()
print(">{}<".format(line))
```

Make sure you do the substitution and reduction steps in your head. Be especially careful about the third line of code. Also, what do you think the special `\t` character is?

Exercise 8-2

The string methods you have tried so far have all returned a new string. Try this example:

```
'ATGACGCGGA'.startswith('ATG')
```

and this

```
'ATGACGCGGA'.endswith('ATG')
```

What do the methods do and what do they return?

Using the Python documentation

Now that you are well underway to becoming a programmer, you should know your way around the Python documentation. Especially the part called the Python standard library. There is a *lot* of details in there that we do not cover in this course. These are mainly tools and techniques that for writing more efficient, extensible, robust and flexible code. The parts we cover in this course are the minimal set that will allow you to write a program that can do *anything*.

Exercise 8-3

There is a string method that returns a secret agent:

```
print('7'.zfill(3))
```

You can look it up in the Python documentation.

Exercise 8-4

Browse through all the string methods to get an impression of all the functionality that is packaged with string objects.

String formatting

You have already tried string formatting in Section 8-1. String formatting is a simple but powerful technique that lets you generate pretty strings from pre-computed values. You may have noticed that every time we print a floating-point number, a lot of decimals are shown. Not very pretty if you are only interested in two decimals anyway. To format a string, you use the `format` method (surprise). In its simplest use, `format` replaces occurrences of `{}` with the arguments that is passed to it - like this:

```
taxon = "genus:{}, species:{}".format('Homo', 'sapiens')
```

Exercise 8-5

What happens if you try this?

```
question = "Was {} {} Swedish?".format('Carl', 'Linneaus')
```

and this?

```
question = "Was {} Swedish?".format('Carl', 'Linneaus')
```

and this?

```
question = "Was {} {} Swedish?".format('Carl Linneaus')
```

In the two last examples the number of `{}` did not match the number of arguments to `format`. What happens when there are too few and what happens when there are too many?

Exercise 8-6

Consider this code:

```
s = "{} is larger than {}".format(4, 3)
print(s)
```

What will happen if you run this code? Write the code and see for yourself once you think you know. If you were wrong, make sure you understand why.

Exercise 8-7

Consider this code:

```
language = 'Python'
invention = 'sliced bread'
s = '{} is the best thing since {}'.format(language, invention)
print(s)
```

What will happen if you run this code? Write the code and see for yourself once you think you know. If you were wrong, make sure you understand why.

Exercise 8-8

Consider this code:

```
my_template = '{} is the best thing since {}'
language = 'Python'
print(my_template.format(language, 'sliced bread'))
```

```
print(my_template.format(language, 1900 + 89))
```

What will happen if you run this code? Do the substitution and reduction steps in your head.

Exercise 8-9

Think back to Section 3-3 where you calculated how many cookies you could buy for 30 kr. The bars are 7 kr. So your program looked something like this:

```
nr_bars = 30 / 7
print('I can buy', nr_bars, 'chocolate bars!')
```

and it ran like this: `python chocolate.py`

I can buy 4.285714285714286 chocolate bars!

String formatting lets you rewrite the program like this:

```
nr_bars = 30 / 7
message = "I can buy {} chocolate bars!".format(nr_bars)
print(message)
```

Try to replace `{}` with `{:.2f}`. `format` reads the stuff after the colon in each set of curly brackets and uses it as directions for how to format the value it inserts. Try it out and see what happens if you change the number 2 to 3, 4, 5 or 10.

Exercise 8-10

See if you can find the documentation for the `format` function in the Python documentation. It can do wondrous things, for this course we will only try to control the number of digits and padding with spaces. Look at the examples below. Maybe you can figure out how it works

```
pi = 3.14159265359
print("{}*".format(pi))
print("{:.3f}*".format(pi))
print("{:.6f}*".format(pi))
print("{:>5.3f}*".format(pi))
print("{:>10.3f}*".format(pi))
```

Exercise 8-11

This is bonus info, rather than an actual exercise. How do you think python can figure out that adding strings with is supposed to work differently than adding numbers? Remember that `'1' + '2'` is `'12'` not `3`. The answer is that all values you can add with the `+` operator has a secret method called `__add__` that defines how adding works for that type of value:

```
s1 = "11"
s2 = "22"
n1 = 11
n2 = 22
print(s1 + s2)
print(s1.__add__(s2))
print(n1 + n2)
print(n1.__add__(n2))
```

This is one of many examples of how objects allow Python to implement functionality that fits each particular type of value. This was just to show how Python does this. Just like yellow and black stripes in nature means “don’t touch me!” – double underscores (__) is Python’s way of saying “do not use this!”. You are supposed to use the + operator not the __add__ method.

Indexing and slicing strings

Another feature of string objects is that they allow you to extract individual parts of the string.

Each character in a string is identified by its *index* in the string. To access a character in a list you write brackets after the string. Between those brackets, you specify the index of the character you want. The first character has index 0, the second has index 1 and so on.

```
codon = 'ATG'
print("first base is", codon[0])
print("second base is", codon[1])
print("third base is", codon[2])
```

You may wonder why the index of the first character is zero and not one. That is simply the convention in programming and is so for good reason. Over time you will begin to find this useful rather than annoying. You should think of the index as the offset from the start of the string.

That also means that the index is not the length of the string, but the length minus one:

```
amino_acids = 'ARNDCQEGHILKMFPSTWYV'
last_index = len(amino_acids)-1
```

```
print("Last amino acid is", amino_acids[last_index])
```

If you want a sub-string from a larger string (we call that a *slice*), you specify a start index and an end index separated by a colon:

```
print(amino_acids[1:4])
```

When you run that you can see that `amino_acids[1:4]` is substituted for `'RND'`, so the slicing operation produces a sub-string of `amino_acids`. You may wonder why the value at index 4 is not in the resulting sub-string. That is another programming convention: intervals are *ends exclusive*. So when you specify an interval with a start index of 1 and an end index of 4 it represents all the characters starting from 1 and up to, *but not including*, 4. So the slice `1:4` corresponds to the characters at indexes 1, 2 and 3. The reason programmers handle intervals in this way is that it makes it easier to write clear and simple code as you will see in the exercises.

Exercise 8-12

What do this expression reduces to?

```
"Futterwacken"[7]
```

Exercise 8-13

What is printed here? Do all the substitution and reduction steps and compare to the exercise above.

```
s = "Futterwacken"  
print(s[7])
```

Exercise 8-14

What is printed here? Do all the substitution and reduction steps – and do it *twice*. Next week you will be happy you did.

```
dna = 'TGAC'
i = 0
print(dna[i])
i = 1
print(dna[i])
i = 2
print(dna[i])
```

Exercise 8-15

What do you think happens here? Make up your mind and try out the code below:

```
s = "Futterwacken"
s[6] = 'W'
```

Did you see that coming? Strings are *immutable*, which means that you cannot change them once you have made them. If you want "FutterWacken" you need to produce a new string with that value. Try to figure out how to do that with the `replace` method of strings.

Exercise 8-16

When you do not specify the start and/or the end of a slice, Python will assume sensible defaults for the start and end indexes. What do you think they are? Make up your mind and try out the code below:

```
s = 'abcdefghijklmnopqrstuvwxyz'
print(s[:11])
print(s[11:])
print(s[:])
```

Exercise 8-17

Find the documentation for how slicing of strings work.

Exercise 8-18

What do you think happens when you specify an index that does not correspond to a value in the list:

```
alphabet = 'abcdefghijklmnopqrstuvwxyz'
print(alphabet[99])
```

Read and make sure you understand the error message. You can try to Google the error message.

Exercise 8-19

Do you think you also get an error when you specify a slice where the end is too high? Try it out:

```
alphabet = 'abcdefghijklmnopqrstuvwxyz'
print(alphabet[13:99])
```

and this:


```
alphabet = 'abcdefghijklmnopqrstuvwxyz'
print(alphabet[10000:10007])
```

I guess that is worth remembering, right?

Exercise 8-20

Which character in a string named `alphabet` does this expression reduce to?

```
alphabet[len(alphabet)-1]
```

Exercise 8-21

Because intervals are “ends exclusive” we can compute the length of a slice as `end - start`:

```
dna = "ATGAGGTCAAG"
start = 1
end = 4
print("{} has length {}".format(dna[start:end], end-start))
```

Figure out what this code would look like if ends were included in intervals.

Exercise 8-22

Another advantage of “ends exclusive” intervals is that you only need one index to split a string in two:

```
s = 'Banana'
idx = 3
beginning = s[:idx]
end = s[idx:]
print(beginning + end)
```

Figure out what indexes you would need to use to split a sequence in two if ends were included in intervals.

Exercise 8-23

Did you look up the details of how slicing works in Section 8-17? Then you should be able to explain what happens here:

```
s = 'zyxvutsrqponmlkjihgfedcba'
print(s[::-1])
```

General exercises

Exercise 8-24

Will this print Bananas rule!? Do all the substitutions and reductions.

```
if 'na' * 2 == "Banana"[2:]:
    print("Bananas rule!")
```

Exercise 8-25

Will this print Bananas rule!? Do all the substitutions and reductions.

```
if "{}s".format('Banana'[1:].capitalize()) == 'Ananas':  
    print("Bananas rule!")
```

Exercise 8-26

Write a function called `even_string` that takes a string argument and returns `True` if the length of the string is an even number and `False` otherwise. E.g. `even_string('Pear')` should return `True` and `even_string('Apple')` should return `False` (remember the modulo operator?).

Exercise 8-27

Look at the code below and decide what is printed at the end. Then write the code and test your prediction. If you are wrong, make sure you figure out why by revisiting the chapter about functions.

```
def enigma(x):  
    if x == 4:  
        return x  
  
result = enigma(5)  
print(result)
```

Exercise 8-28

Inspect the code below and figure out why it does not print that you are a super star. Test the function using various input and figure out the mistake.

```
def even_number(x):  
    if x % 2:  
        return False  
  
if even_number(4):  
    print('You are a super star!')
```

9 Lists of things

This chapter is about lists and dictionaries that are Python values that can contain other Python values. Lists and dictionaries lets you build relationships between values, which is what data structures represent.

Lists

For many kinds of data, the order of things is important. Just like the order of characters is important for the meaning of text in a string, we sometimes we want to specify the order of other things because the relative order of items in the list has some meaning. It could be a grocery list where you have listed the things to buy in the order you get to them in the supermarket. This is where Python lists are useful. When you print a list it nicely shows all the values it contains.

```
grocery_list = ["salad", "canned beans", "milk", 'beer', 'candy']  
print(grocery_list)
```

Unlike strings that can only store the order of characters, lists can contain *any* kind of values and you can mix different types of values any way you like. Here is a list that contains an integer, a boolean, a string and a list:

```
mixed_list = [42, True, 'programming', [1, 2, 3] ]
```

By now you have probably guessed that you make a list with two square brackets. Between them you can put values with commas in-between. A list is a *container* of other values and the value of the list itself does not depend on the values it contains. This makes sense. Otherwise, an empty list would not have a value:

```
my_list = []
```

You can add single values to the end of a list using the append method of lists. Try it out:

```
desserts = []
print(desserts)
desserts.append('Crepe suzette')
print(desserts)
desserts.append('Tiramisu')
print(desserts)
desserts.append('Creme brulee')
print(desserts)
```

If you have a list you want to add to the end of another list you use the extend method:

```
cheeses = ['Gorgonzola', 'Emmentaler', 'Camembert']
desserts.extend(cheeses)
print(desserts)
```

Notice how append and extend *modifies* the existing list instead of producing a new list with the added element.

Exercise 9-1

Do you think this will work?

```
cheeses = ['Gorgonzola',  
           'Emmentaler',  
           'Camembert']  
print(cheeses)
```

Surprised? Code inside parentheses, brackets and braces can span several lines, which can sometimes make your code easier to read.

Exercise 9-2

If you want to test if a value is in a list you use the `in` operator. Try this:

```
print('Tiramisu' in desserts)  
print('Meatloaf' in desserts)
```

Exercise 9-3

You can concatenate two lists to produce a new joined list. Make sure you figure out how this works before you try it out. Then experiment with changing the lists. Can you concatenate two empty lists?

```
some_list = [1, 2, 3]  
another_list = [7, 8, 9]  
merged_list = some_list + another_list  
print(merged_list)
```

This is yet another example of how the functionality of Python objects lets them “know” how to behave under different circumstances, such as when adding two objects (see Section 8-11).

Exercise 9-4

What do you think is printed here? Make sure you figure out how you think this works before you try it out. What does the `append` method return?

```
my_list = []
x = my_list.append(7)
print(x)
print(my_list)
```

Indexing and slicing lists

Now you know how to make lists, but to work with the values in lists you must also know how to access the individual values that a list contains. Fortunately, indexing lists works just like indexing strings: Each value in a list is identified by an *index* exactly like each character in a string:

```
numbers = [7, 4, 6, 2, 8, 1]
print("first value is", numbers[0])
print("second value is", numbers[1])
print("third value is", numbers[2])
```

Notice that the function `len` can also compute the length of a list. So you also get the last value in list like this:

```
numbers = [7, 4, 6, 2, 8, 1]
last_index = len(numbers)-1
print("Last element is", numbers[last_index])
```


If you want a sub-list of values from a list (we also call that a *slice*) you specify a start index and an end index separated by a colon, just like with strings:

```
print(numbers[1:4])
```

When you run that you can see that `numbers[1:4]` is substituted for `[4, 6, 2]`, so the slicing operation produces a new list of the specified values.

Exercise 9-5

What do these two expressions reduce to?

```
[11, 12, 13, 14, 15, 16, 17][2]
```

Exercise 9-6

What is printed here? Do all the substitution and reduction steps and compare to the exercise above.

```
l = [11, 12, 13, 14, 15, 16, 17]
print(l[2])
```

Exercise 9-7

What is printed here? Do *all* the substitution and reduction steps – and do it *twice*. Next week you will be happy you did.

```
numbers = [1,2,3]
i = 0
print(number[i])
i = 1
print(number[i])
i = 2
print(number[i])
```

Exercise 9-8

What do you think happens here? Make up your mind and try out the code below:

```
l = [11, 12, 13, 14, 15, 16, 17]
l[4] = "Donald"
print(l)
```

Were you surprised what happened? Compare to Section 8-15. Lists are not immutable like strings and you can replace values by assigning a new value to an index in the list.

Exercise 9-9

With your knowledge of slicing, what do you think is printed below:

```
l = [11, 12, 13, 14, 15, 16, 17]
print(l[:3])
print(l[3:])
print(l[:])
```

Exercise 9-10

What do you think happens when you specify an index that does not correspond to a value in the list:

```
l = [11, 12, 13, 14, 15, 16, 17]
print(l[7])
```

Read and understand the error message. Does it ring a bell?

Exercise 9-11

Do you think you also get an error when you specify a slice where the end is too high? Try it out:

```
l = [11, 12, 13, 14, 15, 16, 17]
print(l[4:99])
```

I guess that is also worth remembering.

Exercise 9-12

Which value in a list named `l` does this expression reduce to?

```
l[len(l)-1]
```

Exercise 9-13

If you do not like Emmentaler you can just delete it. What do you think the `del` keyword does?

```
cheeses = ['Gorgonzola', 'Emmentaler', 'Camembert']
print(cheeses)
del cheeses[1]
print(cheeses)
```

Exercise 9-14

Because intervals are “ends exclusive” we can compute the length of a slice as `end - start`:

```
l = [7, 4, 6, 2, 8, 1]
start = 1
end = 4
print("{} has length {}".format(l[start:end], end-start))
```

Think about what this code would look like if ends were included in intervals.

Exercise 9-15

Another advantage of “ends exclusive” intervals is that you only need one index to split a list in two:

```
numbers = [1, 2, 3, 4, 5, 6]
i = 3
beginning = numbers[:i]
```

```
end = numbers[i:]  
print(beginning + end)
```

If ends were included in intervals this would not be as simple.

Exercise 9-16

Do *all* the substitution and reduction steps in your head (or on paper) before you write any of the following code. Think carefully and make up your mind what you think will be printed below. Remember that the *value* of a list is a container that holds other *values* in it. Then write the code and see if you were right. If you were not, make sure you figure out what led you to the wrong conclusion.

```
x = 'A'  
y = 'B'  
z = 'C'  
lst = [x, y, z]  
print(lst)  
  
x = 'Preben'  
print(lst) # what is printed here?  
  
lst[0] = 'Mogens'  
print(lst) # what is printed here?
```

Exercise 9-17

Do you remember this trick from string slicing?

```
l = [1, 2, 3, 4, 5]
print(l[:-1])
```

Exercise 9-18

You can produce a list by splitting a long string into smaller parts. Think: *“Hey string, split yourself on this smaller string”*. Try these variations to figure out how it works

```
"Homo sapiens neanderthalensis".split(" ")
"Homo sapiens neanderthalensis".split('en')
'ATGCTCGTAACGACACTGCACTACTACAATAG'.split('')
"1, 2, 3, 5, 3, 2, 5, 3".split(', ')
"1,2,3,5,3,2,5,3".split(',')
'ATGCTCGTAACGACACTGCACTACTACAATAG'.split()
"Homo sapiens neanderthalensis".split()
```

Notice that the method has a default behavior when no argument is passed to it.

Exercise 9-19

You can produce a string by joining the elements of a list (if all the elements are strings of course). Think: *“Hey string, put yourself in between all the strings in this list”*.

```
"-".join(['Homo', 'sapiens', 'neanderthalensis'])
"...".join(['Homo', 'sapiens', 'neanderthalensis'])
"".join(['A', 'T', 'G'])
```

Notice how you can join something on an empty string. This is a very useful technique; for example if you want to turn a list of characters into a string.

General exercises

What does this expression reduce to? 'aaaaa', 'BaBaBa', or 'Banan'. Make up your mind and then run the expression to check.

```
'a'.join('Banana'.split('a')[:3] * 4)[-5:]
```


10 Pairs of things

This chapter is about dictionaries that, like lists, is another Python value that can contain other Python values. Dictionaries lets you build relationships between values, which is what data structures represent.

Dictionaries

Lists are useful for storing values when the order of the values is important but lists have one drawback: you can only access a value in a list using the index of the value.

A dictionary, called dict in Python, is a much more flexible data type. Like a list, a dictionary is a container for other values, but dictionaries do not store values in sequence. They work more like a database that lets you store individual *values*. When you store a value you assign it to a *key* that you can then use to access the stored value. Now create your first dictionary:

```
person = {'name': 'Robert Redford', 'height': 179, 'job': 'Actor'}
```

This dictionary has three values ('Actor', 'Robert Redford' and 179) and each value is associated with a key. Here 'height' is the key for the value 179. So when defining a dictionary you should note the following:

1. You make a dictionary using braces.
2. Between you braces you put key-value pairs separated by a colon.

3. The key-value pairs are separated by commas.
4. To make an empty dictionary you just write the braces with nothing between them: {}.

To access a value in the dictionary you use its key in square brackets after the dictionary:

```
"{} is a {} cm {}".format(person['name'], person['height'], person['job'])
```

Here we used strings as keys, but you can also use many types of values as keys (Python will give you an error if you try to use a type that is not allowed):

```
misc_dict = {42: "Meaning of life", "pi": 3.14159, True: 7}
```

A dictionary stores key-value pairs but does not keep track of their order. So when you print a dictionary the order of the key-values pairs is arbitrary.

If you have a dictionary you can add key-value pairs in this way:

```
person['job'] = 'Retired'  
person['hair'] = 'uniquely combed'  
print(person)
```

Notice that if you assign a value (71) to a key that is already in the dictionary ('age'), then the old value (70) is replaced.

Exercise 10-1

What does this expression evaluate to?

```
{'name': 'Robert Redford', 'height': 179, 'job': 'Actor'}['name']
```

Exercise 10-2

Assuming the definition of the person dictionary above, what does this expression evaluate to? Compare to the expression in the previous exercise.

```
person['name']
```

Exercise 10-3

The *in* operator also works with dictionaries. Look at what these expressions reduce to and then try to figure out what *in* does when applied to a dictionary:

```
'name' in person  
'height' in person  
'job' in person  
84 in person  
'Actor' in person  
'Robert Redford' in person
```

Exercise 10-4

Write and run this code with different values of key and read any error messages.

```
key = 3
# key = 'banana'
# key = 3.14159
# key = True
# key = {}
# key = []
d = {}
d[key] = 7
```

Are any of the values not allowed as keys?

Exercise 10-5

Do you think this will work?

```
person = {'name': 'Robert Redford',
          'height': 179,
          'job': 'Actor'}
print(person)
```

General exercises

Start by making dictionaries for (some of) the Trump family:

```
donald = {'name': 'Donald Trump', 'age': 70, 'job': 'President' }
melania = {'name': 'Melania Trump', 'age': 70, 'job': 'First lady' }
tiffany = {'name': 'Tiffany Trump', 'age': 23, 'job': 'Internet personality' }
ivanka = {'name': 'Ivanka Trump', 'age': 35, 'job': 'Top aide' }
```

Exercise 10-6

What do you think the following code produces? Do *all* of the substitution and reduction steps in your head, and only then try out the code.

```
donald['child'] = tiffany
melania['husband'] = donald

print(melania)
print(melania['husband']['child'])
```

Exercise 10-7

A dictionary can contain *any* kind of Python values, even lists or dictionaries. Consider the code below where we add a list of ex-wives to the Trump persona. Can you see why we need to check if the 'ex-wives' key before we add to the list of ex-wives?

```
donald = {'name': 'Donald Trump', 'age': 70, 'job': 'President' }

if 'ex-wives' not in donald:
    donald['ex-wives'] = []
donald['ex-wives'].append('Marla Maples')
donald['ex-wives'].append('Ivana Trump')

print(donald)
```

Exercise 10-8

In case you wonder what the *type* of value a list is, or a dictionary, try this:

```
print("A list has type:", type([]))
print("A dictionary has type:", type({}))
```

Now the types list and dict are your friends too.

Exercise 10-9

Lists can also contain any kind of value. Consider this example. What do you think the following code produces? Do *all* the substitution and reduction steps in your head, and only then try out the code.

```
trump_family = [donald, melania, ivanka, tiffany]
print(trump_family)
print(trump_family[1]['job'])
```

Exercise 10-10

Write and run this code

```
amino_acids = {}
amino_acids['ATG'] = 'met'
amino_acids['TCT'] = 'ser'
amino_acids['TAC'] = 'tyr'

codon = 'TCT'
print("{} encodes {}".format(codon, amino_acids[codon]))
```

“ You have probably noticed that, for each type of value, the interpretation of length is different. In a string it is the num- ”

“ ber of characters, in a list is the number of values in the list and in a dictionary, it is the number of key-value pairs. How do you think Python knows which interpretation of length to use when the len function is called? This is where objects shine. len(x) just returns the value that x.__len__() returns. So the len function is defined roughly like this:

```
def len(x):  
    return x.__len__()
```

Similarly, the in operator call a secret __contains__ method.

”

11 Gluing values in sequence

Tuples

A tuple is a sequence of values just like a list. However, unlike a list, the elements of a tuple can not be changed. You cannot append to a tuple either. Once a tuple is made it is immutable (or unchangeable). To make a tuple you just use round brackets instead of square brackets:

```
fruits = ("apple", "banana", "cherry")
```

It may seem strange that Python has both tuples and lists. One reason is that whereas lists are more flexible, tuples are more efficient. We will not use tuples a lot, but you need to know what they are.

You can do most of the operations on a tuple that you can also do on a list. The following exercises should be easy if you remember how to do the same thing on lists:

Exercise 11-1

Find the number of elements in the `fruits` tuple using the `len` function.

Exercise 11-2

Extract the second element of the fruits tuple ("banana") using indexing.

Exercise 11-3

Try to change the second element of the fruits tuple to "apple" and see what happens. It should be something like this:

```
Traceback (most recent call last):
  File "script.py", line 2, in <module>
    fruits[3] = "apple"
TypeError: 'tuple' object does not support item assignment
```

You cannot change elements of a tuple because they are immutable (once made, they stay that way).

Tuple assignment

Python lets you assign a tuple of values to a tuple of variables like this:

```
father, mother, son = ("Donald", "Ivana", "Eric")
```

It does the same as the following three assignments:

```
father = "Donald"
mother = "Ivana"
son = "Eric"
```

When a tuple is made, the values are “packed” in sequence:

```
family = ("Donald", "Ivana", "Eric")
```

Using the same analogy, values can be “unpacked” using tuple assignment:

```
father, mother, son = family
```

The only requirement is that the number of variables equals the number of values in the tuple.

Once in a while, it is useful to swap the values of two variables. With conventional assignment statements, we have to use a temporary variable. For example, to swap a and b:

```
tmp = a
a = b
b = tmp
```

Exercise 11-4

Try this and read the error message:

```
family = ("Donald", "Ivana", "Eric")
father, mother = family
```

Exercise 11-5

Try this and read the error message:

```
family = ("Donald", "Ivana", "Eric")  
father, mother, son, daughter = family
```

Compare to the error message in the previous exercise.

Exercise 11-6

Say want to swap the values of two variable a and b. To do that you would need to keep one of the values in an extra variable like this:

```
temp = a  
a = b  
b = temp
```

Can you come up with a simple and pretty way of swapping a and b in one statement, using what you have learned in this chapter? Maybe it occurs to you before you realize how it works, so make sure you can connect your solution to the rules of tuples and tuple assignment.

12 Iteration over values

This chapter is about how you repeat the same code for many different values – and the many reasons why this is useful.

The for-loop

Programs often need to do repetitive things. Consider this example below where `x` is assigned a value that is then printed:

```
x = 1
print(x)
x = 5
print(x)
x = 3
print(x)
x = 7
print(x)
```

You can see that we do the same thing four times with the only difference that the variable `x` takes a new value each time. Now carefully write the alternative version below and compare what is printed to what was printed in the above example.

```
for x in [1, 5, 3, 7]:  
    print(x)
```

It should be exactly the same. What you just wrote is called a *for-loop*. It is called a for-loop because it does something *for* each of many values – in this case for each value in our list.

The statements nested under the for-loop are run as many times as there are values in our list, and every time they are run *x* is assigned a new value. The first time the statements are run, *x* is assigned the *first* value in the list. The second time they are run *x* is assigned the *second* value in the list. This continues until *x* has been assigned all the values in the list.

The semantics of a for-loop is as follows:

1. First, you write *for*.
2. Then you write the name of the variable that will be assigned a new value for each iteration of the loop (*x* in the above case).
3. Then you write *in*.
4. Then you write the name of an *iterable* or an expression that reduces to one. In the above case, it was the list `[1, 5, 3, 7]`.
5. The statements nested under the for loop are indented with four spaces just like with if-statements. These statements are executed once for every value in the *iterable*.

What is an *iterable*, you may ask? Actually, it is any kind of value that knows how to serve one value at a time until there are none left. Only objects that have an `__iter__` method can do this. If you try to iterate over a value that does not have an `__iter__` method you will get an error. Try the code below and see how Python complains that “`int` object is not iterable”:

```
for x in 4:  
    print(x)
```

Try these variations of the for-loop above and notice how the rules 1-5 apply in each case:

```
for x in [1, 5, 3, 7]:  
    print(x)  
  
list_of_numbers = [1, 5, 3, 7]  
for x in list_of_numbers:  
    print(x)  
  
for x in [1, 5] + [3, 7]:  
    print(x)
```

In each case, the expression after `in` reduces to the *value* `[1, 5, 3, 7]`, which then serves as the *iterable*.

Not only lists are iterable. Strings are too. Their `'iter'` method of a string tell it that it should serve once character at a time. Try this:

```
for character in 'banana':  
    print(character)
```

Neat, right?.

In programming, you very often need to iterate over integer values, and sometimes quite a few (like the 250 million bases of the human chromosome one). It would be quite annoying if you had to manually make long lists of integers, so Python provides a builtin function called `range` that helps you out. It returns a special *iterator* value that lets you iterate over a specified range of numbers. Try the two examples below and compare what is printed:

```
total = 0
for number in [0, 1, 2, 3, 4, 5, 6, 7, 8, 9]:
    total += number
print(total)

total = 0
for number in range(10):
    total += number
print(total)
```

You can see that using `range` works just like using a list of numbers, but the cool thing about `range` is that it does not return a list. It just serves one number at a time until it is done. This is also why you will not see a list if you try to print what `range` returns:

```
number_iterator = range(10)
print(number_iterator)
```

The `range` function needs three values to know which values to iterate over: “start”, “end” and “step”. If you do not give it all three arguments it will assume sensible defaults. Try this:

```
for i in range(0, 10, 1):
    print(i)

for i in range(0, 10):
    print(i)

for i in range(10):
    print(i)
```

You can see that the first and the last arguments default to 0 and 1. If you

give it two arguments it will assume that they are “start” and “end”. If you only give it one argument it will assume that it is the “end”.

Exercise 12-1

What do you think the third argument to range specifies? Try these variations and see if you can figure it out:

```
for i in range(0, 10, 1):  
    print(i)  
  
for i in range(0, 10, 2):  
    print(i)  
  
for i in range(0, 10, 3):  
    print(i)
```

Check the documentation once you have made up your mind.

Exercise 12-2

What will happen here:

```
for x in []:  
    print(x)
```

and here:

```
for x in range(0):  
    print(x)
```

and here:

```
for x in range(10, 10):  
    print(x)
```

Exercise 12-3

The two examples below print the same. Make sure you understand why. Write and experiment with the code on your own.

```
list_of_words = ['one', 'two', 'three']  
  
# example 1  
for word in list_of_words:  
    print(word)  
  
# example 2  
list_length = len(list_of_words)  
for index in range(list_length):  
    print(list_of_words[index])
```

Exercise 12-4

Finish the code below so all the even numbers go into one list and all the odd numbers go into the other (hint: remember the modulo operator?)

```
numbers = [4, 9, 6, 7, 4, 5, 3, 2, 6]  
even = []  
odd = []  
for n in numbers:
```

```
# your code here ...
```

Exercise 12-5

You can put any statements under the for-loop. Here it includes an if-statement that lets you generate a list of all the a characters in banana (in case you need that).

```
result = []
fruit = 'banana'
for character in fruit:
    if character == 'a':
        result.append(character)
print(result)
```

Now change the code so you instead get the *indexes* of the 'a' characters: [1, 3, 5]. Here are some hints:

1. You need a for-loop over a list of numbers.
2. `range(len(fruit))` may be relevant numbers :-).
3. `fruit[1]` substitutes for 'a'.

Exercise 12-6

Imagine you want to throw a big party and that you have a rented a place with room for 100 people. Now you want to start inviting people. What kind of error do you get here and why?

```
friends = ["Mogens", "Preben", "Berit"]
invited = []
for index in range(100):
    invited.append(friends[index])
```

Exercise 12-7

You can also put a for-loop under another for loop, and the rules for *each* for loop are still those explained above: The statements nested under the for loop are indented with four spaces just like with if-statements. These statements are executed once for every value in the iterable. Think carefully about what you think is printed in the example below before you try it out.

```
for i in range(3):
    for j in range(3):
        print(i, j)
```

Make sure you understand i, j pairs are printed in the order they are.

13 Working with data files

This chapter covers the bare necessities of how to make your program read data from a file on your computer and how to make it create a file that it can write results to.

Writing files

To interact with a file on your harddisk you need to know the name of the file and whether you want to write to it or read from it. Then you can use the builtin function `open` to create a file object that lets you read or write to that file. The `open` function takes two arguments: The first is a string, which gives the name of the file. The second argument is also a string and should be `'w'` for “write” if you want to write to the file or `'r'` for “read” if you want to read from the file. To keep things simple we will assume that the file you want to open is always in the same folder (directory) as the Python script that calls the `open` function.

Exercise 13-1

Try to write the code below and run it:

```
f = open('workfile.txt', 'w')
f.write("First line\n")
f.write("Second line\n")
```

```
f.close()
```

Now open the `workfile.txt` in *VScode* and see what is in it now. It should contain:

```
First line  
Second line
```

Lets break down what happened:

1. You used the `open` builtin function to open a file called “workfile.txt” in *writing* mode using the `'w'` as the second argument.
2. You then wrote the string `"First line\n"` to the file using the `write` method of the file object.
3. You wrote another string `"Second line\n"` to the file using the `write` method of the file object.
4. You closed the file using the `close` method of the file object.

Note that if you open a file for writing, a file with that name is created. If a file of that name already exist, it is overwritten.

Exercise 13-2

Close `workfile.txt` in *VScode* again and change your program above to this (removing the `\n` characters):

```
f = open('workfile.txt', 'w')  
f.write("First line")  
f.write("Second line")  
f.close()
```

What do you think the content of `workfile.txt` is now? Decide before you open `workfile.txt` in *VScode* again and have a look. What do you think the `\n` character represents?

Exercise 13-3

Close `workfile.txt` in *VScode* and change your program above to this:

```
f = open('workfile.txt', 'w')
f.write("First line\nSecond line\n")
f.close()
```

Can you see how that is equivalent to what you did before? Open `workfile.txt` in *VScode* again and have a look.

Exercise 13-4

You can also make `print` write to a file instead of the terminal. That way your output ends up in the file instead of the terminal. To make `print` write to a file, you need to use the `file` keyword argument to give `print` the file object that represents the file you want to write to (`file=f` below). Try to write the code below and run it:

```
f = open('workfile.txt', 'w')
print("First line", file=f)
print("Second line", file=f)
f.close()
```

Compare the the code to that in Section 13-1. Notice how the strings we `print` do end with a newline. This is because the default behaviour for `print` is to add a newline to the end of what it prints - just like when you `print` to the terminal.

Reading files

When you want to read a from an existing file you give the open function the name of that file and specify 'r' for reading as second argument. If the file you name does not exist, Python will tell you that it does not exist (it is nice like that). Before you head into the next rest of this section make sure you redo Section 13-1 so the content of workfile.txt is:

```
First line  
Second line
```

Exercise 13-5

```
f = open('workfile.txt', 'r')  
file_content = f.read()  
print(file_content)  
f.close()
```

Lets break down what happened:

1. You used the open builtin function to open a file called workfile.txt in *reading* mode using the 'r' as the second argument.
2. You then read the content of the file using the read method, which return the contents as a string.
3. You printed the string.
4. You closed the file using the close method of the file object.

Exercise 13-6

Try to read from the file after you close it:


```
f = open('workfile', 'r')
f.close()
file_content = f.read()
```

Do you get an error? Which one? Do you understand why?

Exercise 13-7

You can use the `readline` method to read one line at a time. What do you think happens if you run this code:

```
f = open('workfile.txt', 'r')
line = f.readline()
print(line)
line = f.readline()
print(line)
line = f.readline()
print(line)
```

Once you decide, try it out. What is printed in the last print statement? The thing is, the file object keeps track of how much of the file it has read. Once it is at the end you can read as much as you like – there is nothing left. If you want to start reading from the top of the file you can close and open the file again. Try to insert the following two statements at various places in the code above and see what happens?

```
f.close()
f = open('workfile.txt', 'r')
```

Exercise 13-8

Look at the code below and figure out for yourself what it does:

```
input_file = open('workfile.txt', 'r')
output_file = open('results.txt', 'w')

for line in input_file:
    line = line.upper()
    output_file.write(line)
```

Then run it and open results.txt in *VScode* and see what it produced.

Were you surprised that the file object can be an iterator in a for-loop? Just like strings can iterate over characters, lists can iterate over values and dictionaries can iterate over keys, file objects can iterate over the lines in the file.

Try to modify your code to use the print function instead of the write method (see Section 13-4).

General exercises

Exercise 13-9

Write a function `read_file` that takes the name of a file as argument. The file should read the content of the file and return it. Like:

```
content_of_file = read_file('some_file.txt')
```

Exercise 13-10

Write a function that takes the name of two files as arguments. The file should read the content of the first file and write it to the second file.

```
copy_file('some_file.txt', 'other_file.txt')
```


14 Structuring data

This section will further train your ability to create such data structures using iteration. Data structures in Python are fundamental tools that allow you to organize, store, and manipulate data effectively. They provide a way to represent and manage data in a structured and organized manner, making it easier to perform various operations on the data. Python offers a variety of built-in data structures, such as lists and dictionaries, with different properties and useful for different needs. Sometimes, a single list or dictionary is all you need. Still, sometimes you need to combine many lists and dictionaries to make elaborate data structure. As your programming skills progress, you will find that mastering the use of different data structures is crucial for becoming a proficient Python programmer.

Exercise 14-1

Imagine you want to count how many times each nucleotide appears in a DNA string like this one: 'ATGCCGATTAA'. One way to proceed an account of this is in the form of a dictionary where the keys represent the different values we want to count (in this case 'A', 'T', 'C' and 'G'). The values associated with each key is the number of times we have seen that key (nucleotide). So we want to end up with a dictionary like this one (not necessarily with key-value pairs in this order):

```
{ 'G': 2, 'C': 2, 'T': 3, 'A': 4 }
```

Remind yourself how you assign a value to an existing key in a dictionary. Here is some code to get you going:

```
dna = 'ATGCCGATTAA'
counts = {'G': 0, 'C': 0, 'T': 0, 'A': 0}
for base in dna:
    # Your code here...
```

Exercise 14-2

In Section 14-1 we started by initializing a dictionary with a key for each nucleotide and the number zero for each key to show that we had not seen any of those nucleotides yet. *Then* we iterated over the values we wanted to count using the for-loop. This approach of course only works if you know which values you will encounter in the iteration. When counting nucleotides, this works because we know there are only four different nucleotides.

Often, however, we are faced with one or both of the following problems:

- The number of different values to count is very large. If we were to count English words, we would have to initialize a dictionary with more than 170,000 key value pairs (which would be somewhat impractical). If we were to count numbers this would be impossible (as there are infinitely many of those).
- We do not know what values we are going to count. It goes without saying that we cannot initialize a dictionary with keys if we do not know what they are.

We can solve this problem by only adding keys for the values we actually see in the iteration. To do this we need to change our approach from before in two ways:

1. We start with an *empty* dictionary.
2. For every value we iterate over, we check if that value is a key in our dictionary. If it is not, then we need to add it and pair it with the value 0. You can test if a key is not in a dictionary using the `not in` operator:

```
if number not in counts:  
    counts[number] = 0
```

Now use these hints to complete the code below so that it counts how many times each number appears in `number_list`.

```
counts = {}  
number_list = [13, 51, 3, 51, 6, 42, 3]  
for number in number_list:  
    # Your code here...
```

When you are done you should have a dictionary like this (possibly with key-value pairs in a different order):

```
{3: 2, 42: 1, 51: 2, 13: 1, 6: 1}
```

Exercise 14-3

The counting technique you developed in Section 14-2 lets you count pretty much anything that can be a key in a dictionary. Try using the same approach to count the number of each thing in this list:

```
stuff = ['sofa', 42, 42, 3.14159, 'sofa', 'Dragon']
```

Exercise 14-4

Instead of counting values, we sometimes need to split the values we iterate over into categories. Here we build a dictionary where the keys are the first letter of each word we iterate over, and the value associated with each key is a list of all the words that start with that letter. So if we iterate over the words in this list:

```
names = ['apricot', 'banana', 'anas', 'apple', 'cherry']
```

we should end up with this dictionary (not necessarily with key-value pairs in that order):

```
{ 'c': ['cherry'], 'a': ['apricot', 'anas', 'apple'], 'b': ['banana'] }
```

Now figure out how to reorder and indent the statements below to produce code that performs this task:

```
names = ['apricot', 'banana', 'anas', 'apple', 'cherry']
words[first_letter].append(fruit)
first_letter = fruit[0]
for fruit in names:
    words = { 'a': [], 'b': [], 'c': [] }
```

Exercise 14-5

Produce the same dictionary as in Section 14-4 by reordering and indenting the following statements:


```

first_letter = fruit[0]
words = {}
words[first_letter].append(fruit)
if first_letter not in words:
    names = ['apricot', 'banana', 'anas', 'apple', 'cherry']
    words[first_letter] = []
    for fruit in names:

```

Compare the solution to that in Section 14-4. How is it different? Is it more generic? How does the difference relate to the difference between Section 14-1 and Section 14-2?

Exercise 14-6

Look at this code and figure make up your mind about what will be printed. Do we first greet one person in three languages or do we first greet all people in one language? Then try it out to see if you were right.

```

greetings = ['Hi', 'Hola', 'Ciao']
names = ['Mogens', 'Preben', 'Henning']
for greeting in greetings:
    for name in names:
        print(greeting, name)

```

Exercise 14-7

Now consider the code below. How is it different from the code in Section 14-6? How does that alter the order of what is printed?

```
greetings = ['Hi', 'Hola', 'Ciao']
names = ['Mogens', 'Preben', 'Henning']
for name in names:
    for greeting in greetings:
        print(greeting, name)
```

Exercise 14-8

Decide what you think the code below does and why you think so. Do *every* step in your head including all the substitutions and reductions. Then write the code carefully and run it.

```
nr_list = [10, 20, 30]
combinations = []
for a in nr_list:
    for b in nr_list:
        pair = [a, b]
        combinations.append(pair)
```

The combinations list becomes:

```
[[10, 10], [10, 20], [10, 30],
 [20, 10], [20, 20], [20, 30],
 [30, 10], [30, 20], [30, 30]]
```

Here I broke over three lines to make it fit on the page. You should print your own combinations list to make sure you got the code right.

Exercise 14-9

The code in Section 14-8 printed all combinations of numbers in the list – including those where the two numbers are the same. Change the code above so these pairs are *not* printed. You should end up with this list:

```
[[10, 20], [10, 30], [20, 10], [20, 30], [30, 10], [30, 20]]
```

Exercise 14-10

Can you solve the same task as in Section 14-9, by modifying the code below? Begin by making sure you understand why it produces the same list as that in Section 14-8. If you have trouble with that, then have another look at Section 12-7.

```
nr_list = [10, 20, 30]
combinations = []
for i in range(len(nr_list)):
    for j in range(len(nr_list)):
        pair = [nr_list[i], nr_list[j]]
        combinations.append(pair)
```

Exercise 14-11

The code in the exercise above printed all combinations of *different* numbers in the list. But you can see that each pair of numbers still appear twice if you do not take their order into account (e.g. [10, 30] are the same two numbers as [30, 10]). Change the code you wrote for the previous exercise so these pairs are not printed. You should end up with a list like this:

```
[[10, 20], [10, 30], [20, 30]]
```

Hint: the easiest way to do it is to use the value of `i` to change the range of numbers you iterate over in the second for-loop.

Exercise 14-12

Sometimes programmers (like you) work with matrices of numbers like the one below:

```
[[0, 1, 2, 3, 4],  
 [0, 1, 2, 3, 4],  
 [0, 1, 2, 3, 4],  
 [0, 1, 2, 3, 4],  
 [0, 1, 2, 3, 4]]
```

Here I wrote the list in a nice way so you can see that a matrix is really just *a list of lists*. When you print it looks like this:

```
[[0, 1, 2, 3, 4], [0, 1, 2, 3, 4], [0, 1, 2, 3, 4], [0, 1, 2, 3, 4], [0, 1, 2,
```

Do you think you can write some code that produces this matrix? If you let out a sigh just now, then reread the sections on lists and for-loops. You may think absorbed all the information you could when you read it the first time, but with your practice since then, you may be able to understand it at a deeper level the second or third time you read it.

The code below produces the matrix above. There are several tricky parts that you need to make sure you understand. In line three we add an empty list to the list of lists. In line five we add the value of `j` to the list at index `i` in the list of lists. Go over this many times in your head and with pen and paper.

```
matrix = []
for i in range(5):
    matrix.append([])
    for j in range(5):
        matrix[i].append(j)
```

Exercise 14-13

If you understand how you created the matrix in Section 14-12, you should be able to produce the matrix below using a small modification to the code from Section 14-12.

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

Exercise 14-14

Now produce this matrix:

```
[[0, 0, 0, 0, 0],
 [0, 0, 0, 0, 0],
 [0, 0, 0, 0, 0],
 [0, 0, 0, 0, 0],
 [0, 0, 0, 0, 0]]
```

Exercise 14-15

Can you write some code that produces this matrix?:

```
[[ 0, -1, -2, -3, -4],  
 [-1, 0, 0, 0, 0],  
 [-2, 0, 0, 0, 0],  
 [-3, 0, 0, 0, 0],  
 [-4, 0, 0, 0, 0]]
```

General exercises

“ By now you have learned a lot and the general exercises, which serve to keep it all current, get more complicated. But remember: even though the code may mix lists, for-loops, and functions, the *rules* for lists, for-loops and functions are *not* mixed. The separate simple rules for a list, a for-loop and a function are *still* the same. If you get confused, it is time revisit the sections about each separate topic. You will probably have to do that many times during the course. ”

Exercise 14-16

Write a function, `square_numbers`, that takes a list of numbers as argument and returns a new list with the numbers squared.

```
# write your function definition here ...
```

```
numbers = [1, 5, 3, 7]

# then you can call it like this:
squared = squared_numbers(numbers)
```

Exercise 14-17

Write a function `count_characters`, which takes a string argument and returns a dictionary with the counts of each character in the string. When you call the function like this:

```
count_characters('banana')
```

it must return (not necessarily with key-value pairs in that order):

```
{ 'n': 2, 'b': 1, 'a': 3 }
```

The technique you should use is the one you learned in Section 14-2. Here we just iterate over a string of characters instead of over a list of numbers. Here is a bit of code to help you along...

```
def count_characters(text):
    counts = {}
    # fill in the missing code ...

    return counts
```

Exercise 14-18

Use the function you made in the previous exercise to construct the following data structure:

```
{ 'banana': {'b': 1, 'a': 3, 'n': 2},  
  'apple': {'a': 1, 'e': 1, 'p': 2, 'l': 1},  
  'ananas': {'a': 3, 's': 1, 'n': 2} }
```

from this list:

```
['banana', 'ananas', 'apple']
```

Here is some code to help you along:

```
my_database = {}  
for word in ['banana', 'ananas', 'apple']:  
    my_database[word] = # you figure this out...
```

Once you are done, what value do you think `my_database['banana']` represents? I.e. what will it reduce to if used in an expression? And what value does `my_database['banana']['a']` represent?

Exercise 14-19

Read the code below and make sure you understand each single step before you write any of it. Revisit previous sections if you must, go look in the Python documentation. *Then* write and run the code - and enjoy that it was exactly what you expected.


```
def get_words(text, search_string):
    hits = []
    for word in text.split():
        if search_string in word:
            hits.append(word)
    return hits

s = 'eenie meenie minie moe'
nie_words = get_words(s, 'nie')
m_words = get_words(s, 'm')

print(' '.join(nie_words))
print(' '.join(m_words))
```

Exercise 14-20

This larger will take you through some of the most common string manipulations. A palindrome is a string that is spelled the same way backward and forwards.

Write a function, `is_palindrome`, which takes one argument:

- A string.

The function must return:

- True if the string argument is a palindrome and False otherwise.

Example usage:

```
is_palindrome('abcba')
```

should return True and

```
is_palindrome('foo')
```

should return False

One approach to this is to run through `s` from the first to the middle character and for each character check if the character is equal to the character at the same index from the right rather than the left. Remember that the first character of a string is at index 0 and the last at index -1, the second character is at index 1 and the second last at index -2 and so forth.

Since you need to run through the string from the first to the middle character you first need to figure out how many characters that corresponds to. Say your palindrome is "ACTGTCA", then the number of indexes you need to loop over with a for loop is:

```
s = "ACTGTCA"  
nr_indexes = len(s)//2
```

Figure out how to make `range()` return indexes you can use to access the characters in the first half of the sequence. Then make a for loop where you iterate over the indexes you get from `range()`. Try to make the for-loop print out the first half of the characters, just to make sure you are using the right indexes.

Once you get this far you need to compare each character from the first half of the corresponding ones starting from the other end of the palindrome. Figure out how to change each index used for the first half to the corresponding index for the other half so you can compare the relevant pairs. (You need to compare index 0 with -1, 1 with -2 and so on...)

Now try to make the for-loop print both the character from the first half and the corresponding character from the other end. If you got the indexes right you will see that the A print with the A from the other end, the C with the C and so on.

Write an if-statement in the for-loop that tests if the two corresponding characters are the same. If the string is a palindrome, then each pair is identical. So as soon as you see a pair which is not identical, you know it is not a palindrome and you can let your function return False like this:

```
if left_character != right_character:  
    return False
```

Remember that the function ends as soon as it encounters a return statement.

If all pairs pass the test, it means that the string is a palindrome, and the function should return True when exiting the for-loop.

15 Unleash your functions

At time of “printing” this chapter was not finished. So I have added some empty pages so you can merge the chapter into the pdf later without messing up the chapter, exercise and page numbers

Recursion

PLACEHOLDER PAGE

Divide and conquer

PLACEHOLDER PAGE

Exercise 15-1

PLACEHOLDER PAGE

16 Testing your code

This chapter is about how you figure out if the code you wrote actually solves the problem in the way you intended. You will be surprised how often that is not the case – even for seasoned programmers.

Why test your code?

There are tons of reasons why you should test your code. Here are what I think are the two most important ones:

1. **Makes you think:** Testing forces you to slow down and think about exactly what the code is supposed to do. By deciding what tests to do before you start coding, you try to anticipate errors and cases that are not covered by the way you want to solve the problem at hand. The notion of falsification is important in science and in coding too. The idea is that you should try to prove that your idea is wrong and only consider it valid only if this process fails. So testing motivates you to think about ways to break their code, thereby helping you solve your programming problem in a way that is general and robust so that it does exactly what you expect it to do.
2. **Gives you peace of mind:** Testing increases your confidence that a function you have written actually works as it is supposed to so that you can now stop thinking about how it is implemented and focus on using it as a component in solving a larger problem. Having set up a series of tests also allows you to change and improve the implementation of your function without having to worry that it

stops working the way it is supposed to. As long as it passes all the tests it should be ok.

Testing of code is a *big* thing in programming. Professionals consistently test their code. In time you will too, but in this course, you will only do the very basic testing yourself. Instead, you will have access to ready-made testing suites made especially for each of your programming projects.

Basic testing

Say that you are asked to make a function that takes a string argument and returns True if that string is a palindrome and False otherwise (hypothetical example). Then you start thinking about which strings should make the function should return True and which should return False. Once you have defined your `is_palindrome` function you can set up some fairly obvious tests like this:

```
print(is_palindrome('123321') == True)
print(is_palindrome('ATGGTA') == True)
print(is_palindrome('ATGATG') == False)
print(is_palindrome('XY') == False)
```

But if you keep thinking, maybe you come up with more tests to cover all the different types of cases you may encounter:

```
print(is_palindrome('12321') == True) # uneven length
print(is_palindrome('121') == True) # uneven length
print(is_palindrome('AA') == True)
print(is_palindrome('A') == True) # single char
```

The project testing utility

To keep you focused on the programming part, each of the programming projects that you will do in this course comes with a ready-made suite of tests of the functions you are asked to implement. So for each function, you can run tests to make sure it implements the behaviour it is supposed to.

Each project comes with two files that you download from the course page. They have their names for a good reason, so do not change them. In the first project about translating DNA, they are called `translationproject.py` and `test_translationproject.py`.

To be able to test your functions, you *must* write your code in the file called `translationproject.py`. To run your code you type this in the Terminal as usual:

```
python translationproject.py
```

To test the functions as you complete each one, you can run the test script `test_translationproject.py` like this:

```
python test_translationproject.py
```

The code in `test_translationproject.py` reads your code in `translationproject.py` and performs a series of tests of each function. When you run the test script four things may happen depending on the state of your code:

Case 1: If you did not yet implement all the functions, the test script will remind you (once for each test) that you did not implement the functions with the names required.

```
*****  
ATTENTION! The following functions are not defined:
```

```
translate_codon
split_codons
translate_orf
```

These functions are either not correctly named (spelled) or not defined at all. They will be marked as FAILED. Check your spelling if this is not what you intend.

Ran 16 tests in 0.000s

OK (skipped=14)

If you have implemented a function but misspelled its name, you will also get this type of reminder. The reminders are meant as a safeguard to ensure that you do not hand in the assignment with missing or misspelled function definitions.

Case 2: If a test for one of the functions you have written fails, the testing is aborted and the script prints some information to help you understand what the problem could be. Say you wrote the function `translate_codon` wrongly so that it always returns `M` for some reason:

```
def translate_codon(codon):
    return 'M' # crazy
```

then you would get this message:

FAILED TEST CASE: test_translate_codon_2

MESSAGE:

The call:

```
translate_codon('TAA')
```

returned:

```
'M'
```

However, it should return:

```
'*'
```

```
=====
Ran 4 tests in 0.001s
```

FAILED (failures=1)

It is now left to you to figure out why your function returns the wrong value when called with these arguments.

Case 3: If you defined all functions correctly and they all work the way they are supposed to, then the test script just prints:

```
Ran 14 tests in 0.140s
```

OK

17 Project: Translating open reading frames

This chapter is about translating DNA into protein. If bacteria can do it, so can you.

In this project you will write the code needed to translate an open reading frame (ORF) on a DNA sequence into the corresponding sequence of amino acids.

You need two project files for the project, which you can download from the course page:

- **translationproject.py** is an empty file where you must write your code.
- **test_translationproject.py** is the test program that lets you test the code you write in translationproject.py.

The file `translationproject.py` is for your code. The file `test_translationproject.py` is the script you use to test the functions you write for this project (see Chapter 16).

In this project you will need a data structure that pairs each codon to the amino acid it encodes. This is an obvious use of a dictionary and at the top of `translationproject.py` I have defined such a dictionary you can use. Defining it outside the functions means that it is visible inside all your functions (unless you define *another* variable called `codon_map` inside a function). Defining variables globally to your program sometimes make

sense if some value can be considered a *constant* in your program and is *never* changed.

“ It is normally very bad programming style to access variables outside functions in this way because it may have all kinds of unexpected side effects across function calls. So make it a rule for yourself that code *inside* a function should never to access variables *outside* the function. The reason we define `codon_map` globally in this project is to help you understand that when Python cannot find a variable inside a function, it looks outside the function to find it. In this project functions will find `codon_map` in this way. However, as I already said, you should *never* do this yourself. The chance that you make an unexpected mistake is overwhelming. ”

Translating a single codon

Write a function, `translate_codon` that takes one argument:

1. A string, which is a codon.

The function should return:

- A string of length one (one character). If the string argument is a valid codon then this letter should be an amino acid letter specified by the `codon_map` dictionary. Note that stop codons are represented by a star ('*'). If the string argument is *not* a valid codon, the function must return '?'.

Example usage:


```
translate_codon('ACG')
```

should return

```
'T'
```

Before you start coding you should always outline for yourself intuitively what you need to do to complete the task at hand. In this case want to translate, or map, between a three letter string, codon, and the corresponding one letter string for the amino acid that the codon corresponds to. Notice that the keys in the `codon_map` dictionary are in upper case, so you must make sure that the keys *you* use are also in upper case. You can translate codon into an upper case version of itself using the `upper()` method.

Try this out first:

```
codon = 'TTG'
amino_acid = codon_map[codon]
print(amino_acid)
```

Now write the function so it uses the string parameter as a key to look up the corresponding amino acid letter and returns this letter. Before you go on, make a function that does only that.

Before you are completely done you need to make your function handle the situation when the argument to the function is not a key in the `codon_map` dictionary. Use an if-else construct to handle the two cases. The boolean expression must test if the function argument is a key in `codon_map`. Remember that you can use the `in` operator to do this.

Splitting an open reading frame into codons

To translate an entire open reading frame into the corresponding amino acid sequence, you need to split the ORF sequence into codons. When we have done that we can translate each codon using the function `translate_codon` you just wrote.

Write a function, `split_codons`, that takes one argument:

1. A string, which is an ORF sequence

The function must return:

- A list of strings. Each string must have length 3 and must represent the-non overlapping triplets in the same sequence as they appear in the string given as argument.

Example usage:

```
split_codons('ATGTATGCCTGA')
```

should return

```
['ATG', 'TAT', 'GCC', 'TGA']
```

Divide the problem into simpler tasks like above. You need to loop over the sequence to perform operations on it. Start by writing a function that prints each character:

```
def split_codons(orf):  
    for i in range(len(orf)):  
        print(orf[i])
```

Now try to figure out how you can modify the function to make it move over the sequence in jumps of three. Look at the documentation for the range function to see how you can make it iterate over numbers with increments of three like this: 0, 3, 6, 9, 12, Modify your function so that it now prints every third character.

What you want is obviously not every third character. You want three characters. I.e. every third character *and* the two characters that come right after. You can use the index in the for loop to get the corresponding codon using slicing. Modify your function so that it prints each codon.

Now all that remains is to put each codon on a list that you can return from the function. You can define a list before your for-loop so you have a list to add codons to.

Translating an open reading frame

Now you can use the two functions `split_codons` and `translate_codon` to write a function that translates an ORF into a protein sequence.

Write a function, `translate_orf`, that takes one argument:

1. A string, which is a DNA sequence.

The function must return

- A string, which is the protein sequence translated from the ORF sequence argument.

Example usage:

```
translate_orf('ATGGAGCTTANCAAATAG')
```

should return

'MEL?K*'

18 Your own type of object

Do you know that type you are? Python objects do, and this chapter is about how they know.

What defines the type of an object?

By now, you know that Python values are objects and that there are different *types* of objects. Strings have type `str`, integers have type `int` and lists have type `list`, just to mention a few of the ones we know. Remember that you can use the built-in `type` function to find out what type an object is. Try this:

```
print( type('banana') )
print( type(4) )
print( type([]) )
```

And as you already know, objects are “data with associated functionality”. Some of this functionality is available in the form of *methods*: For example, the `upper` and `split` methods of string objects, or the `append` and `extend` methods of lists.

Objects also behave sensibly in different contexts: When if you sum two integers (`4 + 6`) you get their sum 6, but if you sum two strings (`'ban' + 'ana'`) you get concatenation of the two strings `'banana'`. The two different types of objects each know how to act with the `+` operator. Another

example is iteration: If you iterate over a string, you get one character at time in order, but if you iterate over a dictionary, you get the keys in the dictionary (in random order). This super convenient context-aware behaviour, is, in fact, also defined as methods, but more about that below.

Each object carries its own data: different numbers, different strings etc., but their *functionality* is shared by all objects of the same type. So all string objects refer to the same definition of the `upper` and `split` methods in the string *type* as graphically illustrated in figure Figure 18.1.

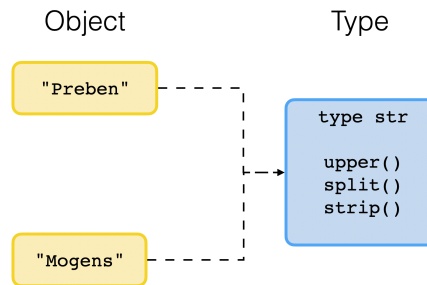


Figure 18.1: Objects and type. Each object carries its own data, but refers to the type for a definition of its methods.

Making your own objects

Imagine if you could create your own types of objects, carrying a particular kind of data and functionality. “Data” can literally represent anything. In bioinformatics it could be an open reading frame, a patient profile, or a tree. Fortunately Python lets us do this using something called *classes*. New kinds of objects and the functionality they provide are defined by classes. So by defining a new class you define a new type of object, and the methods you define in that class are available to objects of the type that particular kind (type).

Lets define a new class, `Point`, that represents a point in a two-dimensional coordinate system. Each such point has an x-value and a y-value as shown in Figure 18.2, so we need our new point object to hold two numbers representing those two values.

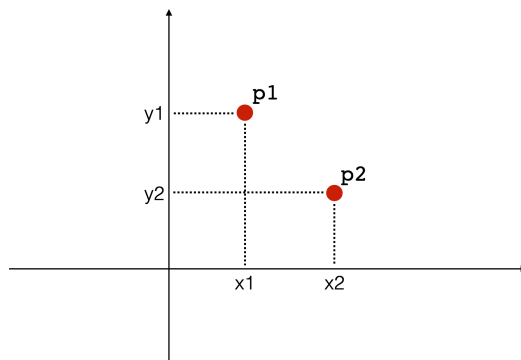


Figure 18.2: Points

Here is how we define the `Point` class:

```
class Point:

    def __init__(self, x, y):
        self.x = x
        self.y = y
```

Let us break it down: We use the keyword `class` followed by the name of class we define. Nested under that statement we can put a

19 Project: Primer analysis

Say you have a short sequence that you want to use as a PCR primer. To evaluate if it is a suitable primer, you need to know the melting temperature of the sequence. You also need to make sure that it will not fold up on itself so that it cannot bind to the DNA sequence you want to amplify.

On the course page you can download the files you need for this project:

- `foldingproject.py` is an empty file where you must write your code.
- `test_foldingproject.py` is the test program that lets you test the code you write in `translationproject.py`.

Put the files in a folder dedicated to this project. On most computers you can right-click on the link and choose “Save file as...” or “Download linked file”.

Count the number of bases in your candidate primer

Before you can compute the melting temperature, you need to determine how many times each base occurs in the sequence. You can assume that the only characters in the string are A, T, G, and C.

Write a function, `count_bases`, which takes one argument:

1. A string, which is a DNA sequence.

The function must return:

- A dictionary, which in which keys are strings that represent bases and values are integers that represent the number of occurrences of each base. If a base is not found in the sequence, its count must be zero.

Example usage: If the function is called like this:

```
count_bases("ATGG")
```

then it should return (not necessarily with key-value pairs in the same order):

```
{"A": 1, "C": 0, "G": 2, "T": 1}
```

Compute the melting temperature

Knowing the base composition in your sequence, you can now calculate the melting temperature the double-stranded DNA that forms when your primer pairs up with the sequence to amplify. If the primer has less than 14 bases the formula for calculating melting temperature is:

$$Temp = (A + T) \cdot 2 + (G + C) \cdot 4$$

and if the primer has 14 bases or more it is calculated like this:

$$Temp = 64.9 + 41 \cdot (G + C - 16.4) / (A + T + G + C)$$

The A, T, C, and G in the formulas represent the numbers of A, T, C and G in the DNA primer.

You must write a function that applies these two formulas appropriately by taking the length of the primer into account.

Write a function, `melting_temp`, which takes one argument:

1. A string, which is a DNA sequence (your primer).

The function must return:

- A number, which represents the melting temperature of the double-stranded DNA corresponding to the DNA string given as argument.

Example usage: If the function is called like this:

```
melting_temp("ATG")
```

then it should return:

```
8
```

Reverse complement the sequence

It is possible that one part of the primer forms base pairs with another part of the primer to form a hairpin structure. To figure out if this can happen to your primer, you need to be able to find the reverse complement of DNA sequence. The reverse complement of a DNA sequence is one where the sequence of bases is first reversed, and then each base is replaced with its Watson-Crick complementary base.

Write a function, `reverse_complement`, which takes one argument:

1. A string, which is a DNA sequence.

The function must return:

- A string, which represents the reverse complement of the DNA string given as argument.

Example usage: If the function is called like this:

```
reverse_complement("AATTC")
```

then it should return:

```
"GAATT"
```

Check for hairpins

You would like to be able to determine if your primer can fold to form a hairpin with some specified minimum number of consecutive base pairs. We assume that hairpin loops are always at least four bases long and that base pairs in the hairpin can only be Watson-Crick basepairs. Here is an example of a hairpin with five basepairs and a loop of four bases (four Cs):

```
      C C
    C      C
    A - T
    T - A
    A - T
    T - A
    A - T
```

To test if a sequence can form a hairpin with at least four consecutive base pairs, you need to test if the sequence contains any subsequence of length four whose reverse complement is identical to another nonoverlapping subsequence. To take into account that the hairpin loop is at least four bases long, any such two subsequences must be separated by at least four bases.

Write a function, `has_hairpin`, which takes two arguments:

1. A string, which is a DNA sequence.
2. An integer, which represents the minimum number of consecutive base pairs in the hairpins to search for.

The function must return:

- True if the sequence contains a hairpin of at least the specified length and False otherwise.

Example usage: If the function is called like this:

```
print(has_hairpin("ATATACCCCTATAT", 4))
```

then it should return:

```
True
```

This is a hard one, so I will give you a bit of help. Here is the function with some parts missing.

```
def has_hairpin(s, k):  
    looplen = 4  
    for i in range(len(s)-k+1):  
        subs = # Hint A  
        right = # Hint B  
        revcl = reverse_complement(subs)
```

```
        if revcl in right[loopleften:]:  
            return True  
    return False
```

Hint A: Here you need to extract a substring of length k starting at i. Hint
B: Here you need to extract all the sequence to the right of substr.

20 Project: Pairwise global alignment

This chapter is about global pairwise alignment and you will implement your own Needleman-Wunch algorithm.

Your task is to find an optimal alignment of two sequences. If two such sequences are both roughly 140 bases long, there are as many different ways to align them as there are atoms in the visible universe, literally. Finding an optimal alignment among those 10^{80} possibilities is obviously a hard problem, but implementing the Needleman-Wunch algorithm will let you do it.

This project is meant to train your coding abilities and consolidate your understanding of the Needleman-Wunch algorithm. The better you understand the algorithm before you begin, the easier and more rewarding the project will be. So re-read the book chapter about pairwise alignment and browse through the lecture slides.

Under “Assignments” on the Blackboard course page, you will find an assignment with the same name as this chapter. There you can download the files you need for this project.

- `alignmentproject.py` is the file where you must write your code. It already contains a function I wrote for you.
- `test_alignmentproject.py` is the test program that lets you test the code you write in `alignmentproject.py`.

Put the files in a folder dedicated to this project. On most computers you can right-click on the link and choose “Save file as...” or “Download linked file”.

The project is split into two parts:

1. Filling in a dynamic programming matrix.
2. Reconstructing the optimal alignment by doing traceback through the dynamic programming matrix.

To help you along, the `alignmentproject.py` file already contains a function I wrote for you so you can print your dynamic programming (DP) matrix as you gradually fill it in. You are not expected to understand how this function works. I tried to make it as condensed as possible so it does not take up so much space in your file.

The function is named `print_dp_matrix` and takes two arguments:

1. A string, which represents a DNA sequence of some length m .
2. A string, which represents a DNA sequence of some length n .
3. A lists of lists of integers, representing a dynamic programming matrix.

The function returns:

- None, but it *prints* a nice representation of the matrix lined with the bases of the two sequences.

Filling in the dynamic programming matrix

Make a matrix

We start out by making a list of lists (a matrix) that has the right shape but only holds None values. We use the None values as place-holders, which

you can later replace with scores. You can think of it as an empty matrix that you can fill scores into, just as we did at the lectures. If you want to align two sequences like AT and GAT you want a matrix that has 3 rows and 4 columns. Note that the matrix must have one more row than the number of bases in sequence one, and one more column than the number of bases in sequence two.

Write a function, `empty_matrix`, that takes two arguments

1. An integer (which represents the length of sequence one + 1).
2. An integer (which represents the length of sequence two + 1).

The function must return:

- A list of lists. The number of sub-lists be must equal to the first integer argument. Each sublist must contain a number of None values equal to the second integer argument.

Example usage:

```
empty_matrix(3, 4)
```

returns a list with *three* lists each of length *four*:

```
[[None, None, None, None], [None, None, None, None], [None, None, None, None]]
```

Even though this is a list of lists we can *think of it* as a three by four matrix:

```
[[None, None, None, None],  
 [None, None, None, None],  
 [None, None, None, None]]
```

If you want to print the matrix in a way that looks like the slides I showed you at the lecture, you can use the `print_dp_matrix` function (again `None` represents empty cells):

```
      G    A    T
None None None None
A None None None None
T None None None None
```

Important: You can implement `empty_matrix` in a way superficially looks ok but will cause you all kinds of grief when you start filling it in. When you create the list of lists (e.g. three lists as above) you need to generate and add three *separate* lists. If you add the *same* list three times you do not have three separate rows in your matrix. Instead you have *three* references to the *same* row. You can test if you did it right this way – by changing the value of one cell to see what happens:

```
empty = empty_matrix(3, 4)
empty[0][0] = 'Mogens'
print(empty)
```

If this only changed *one* value like below, you are ok:

```
[['Mogens', None, None, None], [None, None, None, None], [None, None, None, None]]
```

If it changed the first value in *all* the lists, it means that all your lists are the same (which is not what you want).

```
[['Mogens', None, None, None], ['Mogens', None, None, None], ['Mogens', None, None, None]]
```

Fill top row and left column

Now that you can make a matrix with the correct dimensions, you need to write a function that fills in the top row and the left column in accordance with what the gap score is. E.g. if the gap score is -2 you want the matrix to look something like this when you print it with `print_dp_matrix`:

| | G | A | T |
|---|----|------|------|
| 0 | -2 | -4 | -6 |
| A | -2 | None | None |
| T | -4 | None | None |

Write a function, `prepare_matrix`, which takes three arguments:

1. An integer (which represents the length of sequence one plus one)
2. An integer (which represents the length of sequence two plus one)
3. An integer, which represents the `gap_score` used for alignment.

The function must return:

- A list of lists. The number of sub-lists must be equal to the first integer argument. The values in the first sub-list must be multiples of the gap score given as the third argument. The first elements of remaining sub-lists must be multiples of the gap score. All remaining elements of sub-lists must be `None`.

Example usage:

```
prepare_matrix(3, 4, -2)
```

must return:

```
[[0, -2, -4, -6], [-2, None, None, None], [-4, None, None, None]]
```

Hint: You should call `empty_matrix` inside `prepare_matrix` to get a matrix filled with `None`.

Now all you need to do is replace the right `None` values with *multiples* of the gap score. E.g. the third element in the first sub-list is `matrix[2][0]`, which you would need to assign the value: 2 times the gap score. In the same way `matrix[3][0]` should be 3 times the gap score. So you need to figure out which elements you should replace and which pairs of indexes you need to access those elements. Then use `range` to generate those indexes and `for`-loops to loop over them.

Fill the entire matrix

Now that we are able to fill the top row and left column we can start thinking about how to fill the whole matrix.

For that we need a score matrix of match scores. In Python that is most easily represented as a dictionary of dictionaries like this:

```
score_matrix = {'A': {'A': 2, 'T': 0, 'G': 0, 'C': 0},
                 'T': {'A': 0, 'T': 2, 'G': 0, 'C': 0},
                 'G': {'A': 0, 'T': 0, 'G': 2, 'C': 0},
                 'C': {'A': 0, 'T': 0, 'G': 0, 'C': 2}}
```

That lets you get the score for matching an A with a T like this: `score_matrix['A']['T']`. Note that the match scores are only for uppercase letters (A, T, G, C).

Write a function, `fill_matrix`, which takes four arguments:

1. A string, which represents the first sequence.
2. A string, which represents the second sequence.
3. A dictionary of dictionaries like the one shown above, which represents match scores.

4. An integer, which represents the gap score.

The function must return:

- A list of lists of integers, which represents a correctly filled dynamic programming matrix given the two sequences, the match scores, and the gap score.

Example usage: If `score_matrix` is defined as above then

```
fill_matrix('AT', 'GAT', score_matrix, -2)
```

must return:

```
[[0, -2, -4, -6], [-2, 0, 0, -2], [-4, -2, 0, 2]]
```

If you print that matrix using `print_dp_matrix` it should look like this:

```
      G  A  T
0  -2 -4 -6
A -2  0  0 -2
T -4 -2  0  2
```

Hint: You should call `prepare_matrix` inside `fill_matrix` to get a matrix with the top row and left column filled. Assuming `seq1` is sequence one and `seq2` is sequence two then you can do it like this:

```
matrix = prepare_matrix(len(seq1)+1, len(seq2)+1, gap_score)
```

Now you only need to fill out the rest. To produce the indexes of the elements in the list of lists that you need to assign values to, you need two nested for-loops.

```

for i in range(1, len(seq1)+1):
    for j in range(1, len(seq2)+1):
        print(i, j) # just to see what i and j are

```

Examine this code and make sure you understand why we give those arguments to range. Each combination of i and j let you access an element `matrix[i][j]` in `matrix` (list of lists) that you can assign a value to. The value to assign to `matrix[i][j]` (green cell on the slides) is the maximum of three values (the yellow cells on the slide):

1. The value of the cell to the left (`matrix[i][j-1]`) plus the gap score.
2. The cell above (`matrix[i-1][j]`) plus the gap score.
3. The diagonal cell (`matrix[i-1][j-1]`) plus the match score for base number i (index i-1) of sequence one and base number j (index j-1) of sequence two.

Reconstructing the optimal alignment

This is the most difficult part, so I will hold your hand here. Below is first a function that identifies which of three cells (the yellow cells on the slides) some cell (green cell on the slides) is derived from. On the slides, this is the cell pointed to by the red arrow.

```

def get_traceback_arrow(matrix, row, col, match_score, gap_score):

    # yellow cells:
    score_diagonal = matrix[row-1][col-1]
    score_left = matrix[row][col-1]
    score_up = matrix[row-1][col]

    # green cell:

```

```

score_current = matrix[row][col]

if score_current == score_diagonal + match_score:
    return 'diagonal'
elif score_current == score_left + gap_score:
    return 'left'
elif score_current == score_up + gap_score:
    return 'up'

```

Write (no copy paste) this into your file and make sure that it works and that you understand exactly how it works before you go on.

Here is a function that uses `get_traceback_arrow` to do the traceback. It reconstructs the alignment starting from the last column adding columns in front as the traceback proceeds. It is big, so it breaks across three pages.

```

def trace_back(seq1, seq2, matrix, score_matrix, gap_score):

    # Strings to store the growing alignment strings:
    aligned1 = ''
    aligned2 = ''
    # continues...

    # The row and col index of the bottom right cell:
    row = len(seq1)
    col = len(seq2)

    # Keep stepping backwards through the matrix untill
    # we get to the top row or the left col:
    while row > 0 and col > 0:

```

```

# The two bases we available to match:
base1 = seq1[row-1]
base2 = seq2[col-1]

# The score for mathing those two bases:
match_score = score_matrix[base1][base2]

# Find out which cell the score in the current cell was derived from:
traceback_arrow = get_traceback_arrow(matrix, row, col, match_score, g

if traceback_arrow == 'diagonal':
    # last column of the sub alignment is base1 over base2:
    aligned1 = base1 + aligned1
    aligned2 = base2 + aligned2
    # next cell is the diagonal cell:
    row -= 1
    col -= 1
elif traceback_arrow == 'up':
    # last column in the sub alignment is base1 over a gap:
    aligned1 = base1 + aligned1
    aligned2 = '-' + aligned2
    # next cell is the cell above:
    row -= 1
elif traceback_arrow == 'left':
    # last column in the sub alignment is a gap over base2:
    aligned1 = '-' + aligned1
    aligned2 = base2 + aligned2
    # next cell is the cell to the left:
    col -= 1
# continues...

```



```

# If row is not zero, step along the top row to the top left cell:
while row > 0:
    base1 = seq1[row-1]
    aligned1 = base1 + aligned1
    aligned2 = '-' + aligned2
    row -= 1

# If col is not zero, step upwards in the left col to the top left cell:
while col > 0:
    base2 = seq2[col-1]
    aligned1 = '-' + aligned1
    aligned2 = base2 + aligned2
    col -= 1

return [aligned1, aligned2]

```

Once you have *written* it into your file, make sure you understand the correspondence to the sequences of events on the lecture slides.

Now you can write a function you can call to do perform the alignment. You get to do that yourself. It just calls `fill_matrix` and then `trace_back` to get the optimal alignment

Write a *function*, `align`, that takes four arguments:

1. A string, which represents sequence one.
2. A string, which represents sequence two.
3. A dictionary of dictionaries, which represents the match scores (as described above).
4. An integer, which represents the gap score.

The function must return:

- A list of length two. The first element of that list must be a string, representing the aligned sequence one. The second element must be a string, representing the aligned sequence two.

Example usage:

```
align('ATAT', 'GATGAT', score_matrix, -2)
```

must return:

```
['-AT-AT', 'GATGAT']
```

Once you have written that function you can print your alignment like this:

```
alignment = align('ATAT', 'GATGAT', score_matrix, -2)
for s in alignment:
    print(s)
```

21 Project: Codon usage in *Streptococcus* bacteria

Codon usage bias refers to differences in the frequency of occurrence of synonymous codons in coding DNA. There are 64 different codons (61 codons encoding for amino acids plus 3 stop codons) but only 20 different translated amino acids. The overabundance in the number of codons allows many amino acids to be encoded by more than one codon. Because of such redundancy, it is said that the genetic code is degenerate. Different organisms often show particular preferences for one of the several codons that encode the same amino acid, that is, a greater frequency of one will be found than expected by chance. How such preferences arise is a much-debated area of molecular evolution.

Given an open reading frame (ORF), you must compute the codon usage. Your goal is to create a data structure where you can look up an amino acid and the frequencies of codons in that encode that amino acid the ORF. Here is a made-up example:

```
{ 'A': { 'GCA': 0.0, 'GCC': 0.0, 'GCT': 1.0, 'GCG': 0.0 },  
  'C': { 'TGC': 0.0, 'TGT': 1.0 },  
  'E': { 'GAG': 0.2, 'GAA': 0.8 },  
  'D': { 'GAT': 1.0, 'GAC': 0.0 },  
  'G': { 'GGT': 0.3, 'GGG': 0.0, 'GGA': 0.7, 'GGC': 0.0 },  
  'F': { 'TTC': 0.0, 'TTT': 1.0 },  
  'I': { 'ATT': 1.0, 'ATC': 0.0, 'ATA': 0.0 },  
  'H': { 'CAC': 0.0, 'CAT': 1.0 },
```

```

'K': {'AAG': 0.2, 'AAA': 0.8},
'*': {'TAG': 0.0, 'TGA': 1.0, 'TAA': 0.0}, 'M': {'ATG': 1.0},
'L': {'CTT': 0.0, 'CTG': 0.6, 'CTA': 0.0, 'CTC': 0.0, 'TTA': 0.4, 'TTG': 0.0},
'N': {'AAT': 0.5, 'AAC': 0.5},
'Q': {'CAA': 0.6, 'CAG': 0.4},
'P': {'CCT': 0.5, 'CCG': 0.0, 'CCA': 0.5, 'CCC': 0.0},
'S': {'TCT': 0.0, 'AGC': 0.0, 'TCG': 0.0, 'AGT': 0.5, 'TCC': 0.0, 'TCA': 0.5},
'R': {'CGA': 0.5, 'CGC': 0.0, 'AGA': 0.5, 'AGG': 0.0, 'CGG': 0.0, 'CGT': 0.0},
'T': {'ACC': 0.0, 'ACA': 0.0, 'ACG': 0.0, 'ACT': 1.0},
'W': {'TGG': 1.0},
'V': {'GTA': 0.6, 'GTC': 0.0, 'GTT': 0.2, 'GTG': 0.2},
'Y': {'TAT': 1.0, 'TAC': 0.0}

```

That data structure is a dictionary with keys corresponding to amino acids (i.e. single letter strings designating an amino acid such as 'R' for arginine). The value associated with *each* amino acid key is also a dictionary, and the keys of *this* dictionary should be the different codons that encode the amino acid. The value associated with each codon key should be a number, representing the frequency with which that codon is used to encode that amino acid. The final data structure should only include amino acids that are found in the ORF.

On the course page you can download the files you need for this project:

- sample_orfs.txt contains open reading frame sequences you can work on.

You also need to download the two project files:

- codonbiasproject.py is an empty file where you must write your code.
- test_codonbiasproject.py is the test program that lets you test the code you write in codonbiasproject.py.

Put the files in a folder dedicated to this project. On most computers you can right-click on the link and choose “Save file as...” or “Download linked file”.

Now open each file in *VScode* and have a look at what is in `sample_orfs.txt`. (Do *not* change it in any way and do not save it after viewing. If VScode asks you if you want to save it before closing, say *no*.) How many sequences are there in each file?

As in the translation project, you will need a data structure that pairs each codon to the amino acid it encodes. This is an obvious use of a dictionary and at the top of `codonbiasproject.py` I have defined such a dictionary you can use. Defining it outside the functions means that it is visible inside all your functions (unless you define *another* variable called `codon_map` inside a function). Defining variables globally like this sometimes make sense if some value can be considered a *constant* in your program and is *never* changed.

“ It is normally very bad programming style to access variables outside functions in this way because it may have all kinds of unexpected side effects across function calls. So make it a rule for yourself that code *inside* a function should never to access variables *outside* the function. The reason we define `codon_map` globally in this project is to help you understand that when Python cannot find a variable inside a function, it looks outside the function to find it. In this project, functions will find `codon_map` in this way. However, as I already said, you should *never* do this yourself. The chance that you make an unexpected mistake is overwhelming.

”

The project is split into four parts:

1. Read an open reading frame (ORF) into your script and count the codons.
2. Group the codon counts by the amino acids the codons encode.
3. Convert counts to frequencies.
4. Build the data structure representing the codon bias information.

Read an open reading frame and count its codons

Read ORFs from a file

You can use this code to read the ORFs into your script:

```
f = open('sample_orfs.txt', 'r')
orf_list = list()
for line in f:
    seq = line.strip()
    orf_list.append(seq)
f.close()
```

Try to print the list to see it. Then pick out the first ORF in the list so you can use that to test your code:

```
test_orf = orf_list[0]
```

Split the ORF into codons

You need a function that splits the ORF into codons. This one you have already implemented in the exercise about translating DNA – and if, not here it is in my version to get you started.

```
def split_codons(orf):
    codon_list = []
    for i in range(0, len(orf)-2, 3):
        codon_list.append(orf[i:i+3])
    return codon_list
```

Before you go on, make sure you understand/remember how this function works and what it returns.

Count codons in an ORF

Now you need to count the number of times each codon occurs in the ORF.

Write a function, `count_codons`, that take one argument:

1. A string, which represents the open reading frame.

The function must return:

- A dictionary where keys are strings representing codons and associated values are integers representing the number of times each codon occurs in the ORF given as argument.

Example usage:

```
count_codons("ATGTCATCATGA")
```

should return:

```
{'CTT': 0, 'ATG': 1, 'ACA': 0, 'ACG': 0, 'ATC': 0, 'AAC': 0,
 'ATA': 0, 'AGG': 0, 'CCT': 0, 'ACT': 0, 'AGC': 0, 'AAG': 0,
 'AGA': 0, 'CAT': 0, 'AAT': 0, 'ATT': 0, 'CTG': 0, 'CTA': 0,
```

```
'CTC': 0, 'CAC': 0, 'AAA': 0, 'CCG': 0, 'AGT': 0, 'CCA': 0,
'CAA': 0, 'CCC': 0, 'TAT': 0, 'GGT': 0, 'TGT': 0, 'CGA': 0,
'CAG': 0, 'TCT': 0, 'GAT': 0, 'CGG': 0, 'TTT': 0, 'TGC': 0,
'GGG': 0, 'TAG': 0, 'GGA': 0, 'TGG': 0, 'GGC': 0, 'TAC': 0,
'TTC': 0, 'TCG': 0, 'TTA': 0, 'TTG': 0, 'TCC': 0, 'ACC': 0,
'TAA': 0, 'GCA': 0, 'GTA': 0, 'GCC': 0, 'GTC': 0, 'GCG': 0,
'GTG': 0, 'GAG': 0, 'GTT': 0, 'GCT': 0, 'TGA': 1, 'GAC': 0,
'CGT': 0, 'GAA': 0, 'TCA': 2, 'CGC': 0}
```

– though not necessarily with key-value pairs in that order.

In the function, you should use the `split_codons` function to split the ORF into a list of codons. Then create an empty dictionary that you can populate with counts. You want *all* the possible codons to be in your dictionary. That way, the codons you do *not* find in your ORF will have a count of 0. In this case, such absence is also valuable information. To achieve this you must start by filling the dictionary with a key for each codon and give each a count of 0. You can do that by iterating over the keys in the dictionary that maps codons to amino acids. Then you must iterate over all the codons in the list of codons produced by the `split_codons` function and add counts to the dictionary as you go.

Group codon counts by amino acid

Having counted how many times each codon appears in the ORF, you need to group the counted codons by the amino acid they encode.

Write a function, `group_counts_by_amino_acid`, which takes one argument:

1. A dictionary, as that returned by `count_codons`.

The function must return:

- A dictionary of dictionaries, which pairs each amino acid with a dictionary with counts of how many times each codon is used to encode that amino acid in the ORF.

Example usage: Assuming `counts` is the dictionary returned by `count_codons` as in the previous example.

```
grouped_counts = group_counts_by_amino_acid(counts)
```

then `group_counts_by_amino_acid` should return:

```
{'A': {'GCA': 0, 'GCC': 0, 'GCT': 0, 'GCG': 0},
 'C': {'TGC': 0, 'TGT': 0},
 'E': {'GAG': 0, 'GAA': 0},
 'D': {'GAT': 0, 'GAC': 0},
 'G': {'GGT': 0, 'GGG': 0, 'GGA': 0, 'GGC': 0},
 'F': {'TTC': 0, 'TTT': 0},
 'I': {'ATT': 0, 'ATC': 0, 'ATA': 0},
 'H': {'CAC': 0, 'CAT': 0},
 'K': {'AAG': 0, 'AAA': 0},
 '*': {'TAG': 0, 'TGA': 1, 'TAA': 0},
 'M': {'ATG': 1},
 'L': {'CTT': 0, 'CTG': 0, 'CTA': 0, 'CTC': 0, 'TTA': 0, 'TTG': 0},
 'N': {'AAT': 0, 'AAC': 0},
 'Q': {'CAA': 0, 'CAG': 0},
 'P': {'CCT': 0, 'CCG': 0, 'CCA': 0, 'CCC': 0},
 'S': {'TCT': 0, 'AGC': 0, 'TCG': 0, 'AGT': 0, 'TCC': 0, 'TCA': 2},
 'R': {'AGG': 0, 'CGC': 0, 'CGG': 0, 'CGA': 0, 'AGA': 0, 'CGT': 0},
 'T': {'ACC': 0, 'ACA': 0, 'ACG': 0, 'ACT': 0},
 'W': {'TGG': 0},
 'V': {'GTA': 0, 'GTC': 0, 'GTT': 0, 'GTG': 0},
 'Y': {'TAT': 0, 'TAC': 0}}
```

– though not necessarily with key-value pairs in that order.

So if we pretend the resulting dictionary of dictionaries is called `d`, then `d['S']` will be a dictionary where keys are codons encoding the ‘S’ amino acid and the values are the counts of those codons. That means that you can access a particular count like this:

```
d['S']['TCA']
```

In the above example, this count is 2. So the task is really just to distribute counts given as the first argument into groups for each amino acid. Depending on what you call your variables it could look something like this:

```
grouped_counts[acid][codon] = codon_counts[codon]
```

Your function should begin by defining an empty dictionary to add to. Then use a for-loop to run through all codon/amino-acid pairs and populate your dictionary of dictionaries.

Turn counts into frequencies

Now you know how many times each codon represents a certain amino acid, but we would like to know with which *frequency* a certain codon represents an amino acid. So you need to normalize the counts so they become frequencies. You do that by dividing each codon count by the total number of codons encoding the same amino acid. We split the solution to this problem in two. We first write a helper function that turns codon counts for *one* amino acid into frequencies.

Write a function, `normalize_counts`, which takes one argument:

1. A dictionary, where keys are strings representing codons and values are integers representing the counts of these codons.

The function must return:

- A dictionary, where keys are strings representing codons and values are floats representing the frequency at which each codon appear. That is, the count of that codon divided by the total of all codon counts in the dictionary. The frequencies for codons that encode the same amino acid must of sum to one. That means that in cases where the total count is zero, the function must return None.

Example usage:

```
normalize_counts({'ATT': 8, 'ATC': 10, 'ATA': 2})
```

should return:

```
{ 'ATC': 0.5, 'ATA': 0.1, 'ATT': 0.4 }
```

– though not necessarily with key-value pairs in that order.

Now you have solved part of the task, what remains is to now use that function to normalise the codon counts of *each* amino acid in your grouped counts:

Write a function, `normalize_grouped_counts`, which takes one argument:

1. A dictionary of dictionaries, as that returned by `group_counts_by_amino_acid`.

The function must return:

- A new dictionary of dictionaries where the values of the inner dictionaries are frequencies instead of counts as in the example in the introduction. You should not include amino acids for which there are no counted codons.

Example usage: Assuming `gr_counts` is the dictionary of dictionaries returned by `grouped_group_counts_by_amino_acid` in the example above.

```
normalize_grouped_counts(gr_counts)
```

should return:

```
{'*': {'TAA': 0.0, 'TGA': 1.0, 'TAG': 0.0},
'M': {'ATG': 1.0},
'S': {'AGC': 0.0, 'TCG': 0.0, 'TCC': 0.0, 'TCT': 0.0, 'AGT': 0.0, 'TCA': 1.0}}
```

– though not necessarily with key-value pairs in that order.

Here is some help to get you started:

```
def normalize_grouped_counts(grouped_counts):
    grouped_freqs = {}
    for aa in grouped_counts:
        counts = grouped_counts[aa]
```

Amino acids with no codon counts should *not* be part of the data structure. Remember that in this case `normalize_counts` returns `None`, so you can simply test if the return value from `normalize_counts` is `None`

Compute the codon usage

Now all that remains is to tie together the functions you have written in a final function that generates your big data structure from an ORF:

Write a function, `codon_usage`, which takes one argument:

1. A string, which is an ORF.

The function must return:

- A dictionary of dictionaries, same as that returned by `normalize_grouped_counts`.

22 Project: Identifying the subtype of an HIV sequence

This chapter is a programming project where you will put your new programming skills to use analyzing an HIV DNA sequences.

You have now been introduced to all the programming rules you will see in this course. You now know all the building blocks required to write *any* program – literally *any*. The reason why computer geeks are good at what they do is not that they know some incomprehensible secrets. It is because they practiced, a lot. With practice, the simple rules you know now will let you write anything from first-person shooter games over jumbo jet autopilots to scripts for simple problems in bioinformatics. In the last three chapters, we will train your ability to solve bioinformatics problems by putting together all the things you have learned.

The programming project in this chapter deals with DNA sequences from HIV viruses. There are two types of HIV: HIV-1, which is by far the most common, and HIV-2, which is mostly found in West Africa. HIV-1 viruses are divided into groups M, N, O, and P. The most important group M (for major) is one primarily responsible for the global epidemic. Group M is further divided into subtypes A, B, C, D, F, G, J, K, and CRFs. In this project we will look at sequences from the subtypes A, B, C, and D. You have multiple database sequences for each of these four subtypes and you have one *unknown* sequence from a patient that you need to assign to either subtype A, B, C or D. To do this you will have to write a program that *predicts* the subtype of the unknown sequence. How cool is that?

On the course page you can download the files you need for this project:

- `unknown_type.txt` contains an HIV sequence of unknown subtype
- `subtypeA.txt` contains a database of HIV sequences of subtype A
- `subtypeB.txt` contains a database of HIV sequences of subtype B
- `subtypeC.txt` contains a database of HIV sequences of subtype C
- `subtypeD.txt` contains a database of HIV sequences of subtype D

You also need to download the two project files:

- `hivproject.py` is an empty file where you must write your code.
- `test_hivproject.py` is the test program that lets you test the code you write in `hivproject.py`.

Put the files in a folder dedicated to this project. On most computers you can right-click on the link and choose “Save file as...” or “Download linked file”.

Now open each file in *VScode* and have a look at what is in the data files. (Do *not* change them in any way and do not save them after viewing. If VScode asks you if you want to save it before closing, say *no*.) How many sequences are there in each file?

The project is divided into the following parts:

- Compute the similarity of two sequences
- Read the HIV sequences into your program.
- Assess the similarity of your unknown HIV sequence to each of the HIV sequences with known subtype.
- Find the maximum similarity of your unknown sequence to sequences from each subtype.
- Identify the HIV subtype of your sequence as the subtype of that sequence that your sequence is most similar to.

Make sure you read the entire exercise and understand what you are supposed to do before you begin!

Compute the similarity of two sequences

We need to compare our unknown HIV sequence to all the HIV sequences of known subtypes. That way we can identify the sequence of a known subtype that is most similar to your unknown sequence. We will then assume that our unknown sequence has the same subtype as this sequence. To accomplish this we first need to write some code that compares two sequences so we can compare our HIV sequence to each of the other HIV sequences.

Compare two sequences

Write a function `sequence_similarity` that takes two arguments:

1. A string which is a DNA sequence.
2. A string of the same length as argument one, which is also a DNA sequence.

The function must return:

- A float, which is the proportion of bases that are the same in two DNA sequences.

Example usage:

```
sequence_similarity('AGTC' 'AGTT')
```

should return 0.75.

Start out defining your function like this:

```
def sequence_similarity(seq1, seq2):  
    # your code here...
```

Remember that `range(len(seq1))` generates the numbers you can use to index the string `seq1`. You can use those numbers as indexes to look up positions in both strings. You will need a for-loop in your function and a variable that keeps track of how many similarities you have seen as you iterate through the sequences.

Compare aligned sequences

All sequences, including the unknown sequence, are from the same multiple alignment. This ensures that sequence positions match up across all sequences but also means that a lot of gap characters ('-') are inserted. To compute similarities between such sequences you need to make function much like `sequence_similarity` that does not consider sequence positions where both bases are a gap ('-') characters. In other words, you must not only count the number of characters that are the same, you also need to count how many alignment columns that are "-" for both sequences. E.g. the following mini alignment has five such columns and four columns where the bases are the same. So in the following alignment, the similarity is 0.8 (4/5):

```
A-CT-A
A-CTTA
```

Write a function `alignment_similarity` that takes two arguments:

1. A string which is a DNA sequence with gap characters.
2. A string of the same length as argument one, which is also a DNA sequence with gap characters.

The function must return:

- A float, which is the proportion of bases that are the same in two DNA sequences.

```
alignment_similarity('A-CT-A', 'A-CTTA')
```

should return 0.8.

Hint: Use an if-statement to test if the two characters at some index are equal to '-' in both sequences. You can use an expression like this:

```
seq1[i] == '-' and seq2[i] == '-'
```

Once your function has computed both the number of identical bases and the number of alignment columns that are not both '-', you can have it return the similarity as the ratio of the two.

Read the HIV sequences into your program

To use your `alignment_similarity` function to assess similarity between your unknown sequence and the sequences of known subtype, you need to read the sequences into your program. Here is a function that will read the sequences from one of the files you downloaded into a list:

```
def read_data(file_name):
    f = open(file_name)
    sequence_list = list()
    for line in f:
        seq = line.strip()
        sequence_list.append(seq)
    f.close()
    return sequence_list
```

You can use that function to read the unknown sequence into your program:

```
unknown_list = read_data('unknown_type.txt')
```

In this case, the list only contains the one unknown HIV sequence in unknown_type.txt.

You also need to load the typed HIV sequences into your program. Here is a function that returns a dictionary in which the keys are subtypes ('A', 'B', 'C' and 'D') and each value is a lists of sequences with that subtype:

```
def load_typed_sequences():  
    return {'A': read_data('subtypeA.txt'),  
           'B': read_data('subtypeB.txt'),  
           'C': read_data('subtypeC.txt'),  
           'D': read_data('subtypeD.txt') }
```

If you use the function like this:

```
typed_data = load_typed_sequences()
```

then you can access the list of sequences of subtype A like this: typed_data['A'].

Compare your HIV sequence to HIV sequences of known subtype

To type you HIV sequence you must compare your sequence to all the database sequences to see which group has the best matching sequence.

Write a function get_similarities *that takes two arguments:*

1. A string, which is your unknown HIV sequence.
2. A list of strings, each of which is an HIV sequence of known type.

The function must return:

- A list of floats, which should be the similarities between the unknown sequence given as the first argument and the list of sequences given as the second argument.

Example usage:

```
get_similarities(unknown_list[0], typed_data['A'])
```

should return:

```
[0.8553288474061211, 0.8721742704480066,  
0.854924397221087, 0.8481709291032696,  
0.8498330281159108]
```

The function should use the function `alignment_similarity` to compare your unknown sequence (`unknown_list[0]`) to each of the sequences of some subtype. Start out like this:

```
def get_similarities(unknown, typed_sequences):  
    # Your code here...
```

In your function you need to define a list that you can *append* the similarities you compute to:

```
similarities = []
```

This is the list of results that your function must return. To compute the similarity between you unknown sequence and each of the sequences of

known subtype, you can use your `alignment_similarity` function inside a for-loop.

Compute maximum similarity to each subtype

To predict the subtype of the unknown HIV sequence you need to compare the unknown sequence to all the sequences of each of the different subtypes. The subtype of the sequence with the highest similarity to your unknown sequence is then our predicted subtype (or our best guess).

Write a function `get_max_similarities` that takes two arguments:

1. A string, which is your unknown HIV sequence.
2. A dictionary, like the one returned by `load_typed_sequences`.

The function must return:

- A dictionary, in which keys are strings representing each subtype ('A', 'B', 'C', and 'D') and values are floats representing the maximum similarity between the unknown sequence and the sequences of a subtype. The dictionary *could* look like this (it does not, you need to compute the similarities yourself.):

```
{ 'A': 0.89, 'B': 0.95, 'C': 0.82, 'D': 0.99 }
```

To get the highest number in a list of numbers, you can use the `max` function in Python. It works like this:

```
numbers = [3, 8, 53, 12, 7]
print(max(numbers)) # prints 53
```

For example, to get the highest similarity between the unknown sequence and sequences in `typed_data['A']`:

```
subtypeA_similarities = get_similarities(unknown_list[0], typed_data['A'])
subtypeA_max = max(subtypeA_similarities)
```

Identify the HIV subtype

Now for the grand finale! You ultimately want to be able to write code like this:

```
unknown_list = read_data('unknown_type.txt')
typed_data = load_typed_sequences()
subtype = predict_subtype(unknown_list[0], typed_data)
print("Patient HIV is subtype {}".format(subtype))
```

So all you need now is the `predict_subtype` function.

Write a function `predict_subtype` that takes two arguments:

1. A string, which is your unknown HIV sequence.
2. A dictionary, like the one returned by `load_typed_sequences`.

The function must return:

- A string of length one (either 'A', 'B', 'C', or 'D') representing the predicted subtype of your unknown HIV sequence.

The function should use `get_max_similarities` to compute the dictionary of max similarities and then extract from that dictionary the key with the highest value (similarity). So the function must return 'A' if the unknown sequence is most similar to a sequence of subtype A, 'B' if the unknown sequence is most similar to a sequence of subtype B and so on.

23 Project: Clustering sequences based on distance

This chapter is about clustering sequence based on the evolutionary distance between them.

On the course page you can download the files you need for this project:

- `seqdistproject.py` is an empty file where you must write your code.
- `test_seqdistproject.py` is the test program that lets you test the code you write in `translationproject.py`.

Put the files in a folder dedicated to this project. On most computers you can right-click on the link and choose “Save file as...” or “Download linked file”.

Measuring sequence distance

Clustering is based on the distances between all pairs of sequences. So before you can build your tree you must compute those distances and fill them into a table like that in the book. Here we break that task into three parts:

1. Compare two sequences
2. Make the Jukes-Cantor correction

3. Generate a (lower triangular) distance matrix

Compare two sequences

The first function you must write is one that finds the proportion of different bases between two sequences:

Write a function, sequence_difference, which takes two arguments:

1. A string, which represents a DNA sequence.
2. A string, which represents a DNA sequence of the same length as argument one.

The function must return:

- A float, which represents the proportion of different bases between the two sequences.

Example usage:

```
sequence_difference('AAATTAAA', 'AAAAAAAA')
```

should return

```
0.25
```

Make the Jukes-Cantor correction

To take into account that some substitutions may fall on top of others you must do the Jukes-Cantor correction you read about in the book. The formula is like this:

$$K = \frac{3}{4} \ln\left(1 + \frac{4}{3} D\right)$$

Where D is the proportion of differences as returned by `sequence_diff` and K is the Jukes-Cantor corrected distance. In the top of `seqdistproject.py` it already says:

```
from math import log
```

That line makes the `log` (logarithm) builtin function from the `math` python library available to your programme. Try to find its Python documentation to see how you use it.

Write a function, `jukes_cantor`, which takes one argument:

1. A float, which represents a proportion of different bases between two sequences.

The function must return:

- A float, which represents the Jukes-Cantor corrected distance corresponding the proportion of differences given as argument.

Example usage:

```
jukes_cantor(0.1)
```

should return

```
0.10732563273050497
```

Lower triangular distance matrices

This project is all about distances between pairs (of sequences), and what would be more natural than to put all the distances in a matrix so you can look up the distance between the sequences with indexes *i* and *j* as the matrix element in row *i* and column *j*. You already know how matrices can be represented by lists of lists. E.g. a matrix like this:

can be expressed as a list of lists like this:

```
[[0.0, 0.1, 0.3, 0.3, 0.1, 0.2],  
 [0.1, 0.0, 0.2, 0.4, 0.1, 0.1],  
 [0.3, 0.2, 0.0, 0.4, 0.2, 0.3],  
 [0.3, 0.4, 0.4, 0.0, 0.2, 0.1],  
 [0.1, 0.1, 0.2, 0.2, 0.0, 0.1],  
 [0.2, 0.1, 0.3, 0.1, 0.1, 0.0]]
```

Notice how the diagonal is all zeros because these distances represent the distance of a sequence to itself. Also, notice that the part above the diagonal is a mirror the part below the diagonal (in bold). This is all a bit redundant, especially in this project where you will have to reduce the matrix as you group (or cluster) sequences together. We want something nice and lean where we only have the numbers we need – and that is the *lower triangular matrix*:

```
0.1  
0.3 0.2  
0.3 0.4 0.4  
0.1 0.1 0.2 0.2  
0.2 0.1 0.3 0.1 0.1
```

In Python this is still just a list of lists, only, each sublist now has the same length as its index in the big list (E.g. `[0.3, 0.2]` has index 2 in the list and has length 2):

```
matrix = [[,
           [0.1],
           [0.3, 0.2],
           [0.3, 0.4, 0.4],
           [0.1, 0.1, 0.2, 0.2],
           [0.2, 0.1, 0.3, 0.1, 0.1]]
```

Here I am just writing it nicely. If you where to print that list of lists it would look like this:

```
[[], [0.1], [0.3, 0.2], [0.3, 0.4, 0.4], [0.1, 0.1, 0.2, 0.2], [0.2, 0.1, 0.3, 0.1, 0.1]]
```

Say your sequences had names: A, B, C, D, E, and F, then the above data structure represents distances between each pair like this:

```
A
B 0.1
C 0.3 0.2
D 0.3 0.4 0.4
E 0.1 0.1 0.2 0.2
F 0.2 0.1 0.3 0.1 0.1
  A   B   C   D   E   F
```

There is only one drawback with this reduced representation of the full square matrix: In the full matrix you can get the distance between the sequences with indexes *i* and *j* as *both* `matrix[i][j]` and `matrix[j][i]` because the part above and below the diagonal are the same. Using the lower triangular matrix, you must always use the *largest* index first. Using the smaller one first will give you an `IndexError`. So if you want the distance between sequences with index 2 and 4, you must use the bigger index first (as the row index): `matrix[4][2]`.

Generate a distance matrix

Write a function, `lower_trian_matrix`, which takes one argument:

1. A list of strings. All strings have equal length and represent DNA sequences.

The function must return:

- A list of lists of floats, which represent the lower triangular matrix of Jukes-Cantor distances between DNA sequences given as argument.

Example usage:

```
sequences = ['TAAAAAAAAA',
             'TTAAAAAAAA',
             'AAAAAAAAAGG',
             'AAAAAAAAAGGG']
lower_trian_matrix(sequences)
```

here `lower_trian_matrix` should return:

```
[[],
 [0.08833727674228764],
 [0.30409883108112323, 0.4408399986765892],
 [0.6081976621622466, 0.8239592165010822, 0.18848582121067953]]
```

You should use `sequence_difference` to compute the proportion of differences between each pair of sequences and `jukes_cantor` to produce the corrected distance to fill into the matrix.

Start by figuring out what pairs of indexes you need and then figure out how you can make two nested for-loops generate them. Remember that the length of each sublist is equal to its index in the big list.

Clustering

Now that you have the distance matrix you are ready for the actual clustering. There are three steps to that:

1. Find the pair you want to join
2. Compute the distances between the joined pair and all other elements (linkage)
3. Keep going until you only have one left

Depending on how you choose which pair to join and how you compute the new distances for the joined pair determines what kind of clustering you do. Here we will try a centroid-like linkage called WPGMA. It does not work as well as UPGMA but is a bit easier to implement (you can look up WPGMA on wikipedia).

Find the pair to join

Here you want to be able to find the pair with the smallest distance. To do that we identify the cell in the matrix with the smallest value:

Write a function, `find_lowest_cell`, which takes one argument:

1. A list of lists, which represents a lower triangular distance matrix as returned by `lower_trian_matrix`.

The function must return:

- A list of two integers, which represent the row and column index of the cell with the smallest value in the matrix.

Remember that the row index is always smaller than the column index. The two indexes tell you which two elements to join next.

Example usage: Assuming that `matrix` is the lower triangular matrix returned by `lower_trian_matrix` in the previous example, then

```
find_lowest_cell(matrix)
```

Should return

```
[1, 0]
```

Decide on a linkage method

You also need a function that computes a new distance from two original ones using the the centroid-like linkage we have decided to use.

Write a function, `link`, that takes two arguments:

1. A float, which represents a matrix element.
2. A float, which represents another matrix element.

The function must return:

- A float, which is the average of the two arguments

Example usage:

```
link(0.4, 0.2)
```

Should return:

```
0.3
```


Perform the clustering

The three functions that do the actual clustering are complicated but you should be able to follow what they do. The first one updates the table to reflect that you join a pair. The second updates the list of sequence names (labels) to reflect that you joined a pair. The last one uses the two other functions to cluster pair until there is only one cluster left.

Your task is to carefully type the code for each function and to understand what every line of code does.

Updating labels

The function `update_labels` takes three arguments:

1. A list of strings representing sequence names.
2. An integer representing the index of a sequence name.
3. An integer representing the index of another sequence name.

The function does not return anything, but it updates the list of names to reflect that you joined a pair. If your list looks like this *before* you call the function:

```
labels = ['A', 'B', 'C', 'D']
```

Then *after* you call the function like this `update_labels(labels, 1, 0)`, the list will look like this:

```
['(A,B)', 'C', 'D']
```

Here is the function:

```
def update_labels(labels, i, j):

    # turn the label at first index into a combination of both labels
    labels[j] = "({},{})".format(labels[j], labels[i])

    # Remove the (now redundant) label in the first index
    del labels[i]
```

Updating the matrix

The function `update_table` takes three arguments:

1. A list of lists, which represents a lower triangular distance matrix.
2. An integer representing the index of one of the elements to join.
3. An integer representing the index of the other element to join.

The way this function is implemented, it is assumed that the second argument is always larger than the third argument. I.e. the second argument is a row index and the third argument is a column index.

The function does not return anything, but it updates the matrix to reflect that a pair has been joined. If your matrix looks like this *before* you call the function:

```
m = [[], [0.1], [0.3, 0.4], [0.6, 0.8, 0.2]]
```

Then *after* you call the function like this `update_table(m, 1, 0)`, the matrix will look like this:

```
[[], [0.35], [0.7, 0.2]]
```

Here is the function:

```

def update_table(table, a, b):

    # For the lower index, reconstruct the entire row (ORANGE)
    for i in range(0, b):
        table[b][i] = link(table[b][i], table[a][i])

    # Link cells to update the column above the min cell (BLUE)
    for i in range(b+1, a):
        table[i][b] = link(table[i][b], table[a][i])

    # Link cells to update the column below the min cell (RED)
    for i in range(a+1, len(table)):
        table[i][b] = link(table[i][b], table[i][a])

    # Delete cells we no longer need (lighter colors)
    for i in range(a+1, len(table)):
        # Remove the (now redundant) first index column entry
        del table[i][a]
    # Remove the (now redundant) first index row
    del table[a]

```

The colors refer to cell colors on the slide you I showed you at the lecture.

Do the clustering

Now onto the real task, the actual clustering. The function `cluster` takes two arguments:

1. A list of strings representing DNA sequences of equal length.
2. A list of strings representing sequence names.

The function returns:

- A string representing the generated clustering.

Here is the function:

```
def cluster(sequences, names):

    table = lower_trian_matrix(sequences)
    labels = names[:]

    # Until all labels have been joined...
    while len(labels) > 1:
        # Locate lowest cell in the table
        i, j = find_lowest_cell(table)

        # Join the table on the cell co-ordinates
        update_table(table, i, j)

        # Update the labels accordingly
        update_labels(labels, i, j)

    # Return the final label
    return labels[0]
```

Here is a simple example of how you can use your new clustering code:

```
names = ['A', 'B', 'C', 'D']
sequences = ['TAAAAAAAAA',
            'TTAAAAAAAA',
            'AAAAAAAAAGG',
            'AAAAAAAAAGGG']

tree = cluster(sequences, names)
print(tree)
```

On your own

From here on you are on your own. If you find a FASTA file with aligned (ungapped) homologous sequences, you can use the function below to read it into your program and try your code out on real-world sequences. I will leave it to you to figure out how it works.

```
def read_fasta(filename):
    f = open(filename, 'r')
    record_list = []
    header = ""
    sequence = ""
    for line in f:
        line = line.strip() ## get rid of whitespace and newline
        if line.startswith(">"):
            if header != "": ## if it is the first header
                record_list.append([header, sequence])
                sequence = ""
            header = line[1:]
        else:
            sequence += line
    record_list.append([header, sequence])
    return record_list
```


24 Using code from other files

This chapter is about ...

A module is a file with code

25 Project: Finding genes in bacteria

This chapter is a programming project where you will find open reading frames in the genome of a particularly virulent strain of E. coli.

In this project, you will analyze DNA to identify the open reading frames (ORFs) and the proteins they encode.

On the course page you can download the files you need for this project:

- `e_coli_0157_H157_str_Sakai.fasta` contains the full genome of the *Escherichia coli* O157:H7 Sakai strain (yes the full genome).

You also need to download the two project files:

- `orfproject.py` is an empty file where you must write your code.
- `test_orfproject.py` is the test program that lets you test the code you write in `orfproject.py`.

Put all three files in a folder dedicated to this project. On most computers you can right-click on the link and choose “Save file as...” or “Download linked file”.

For your convenience, the file `orfproject.py` already contains three global *constants* (variables that must never be changed by the code). One is a dictionary `codon_map`, which maps codons to letters that represent amino acids. The other two are a string, `start_codon`, and a list,

stop_codons. You can refer to these three variables in your code, but obviously, never change them.

The project has three parts.

1. In the first part of the project, you will write the code necessary to identify ORFs in a long genomic sequence.
2. In the second part, you will use the code you wrote on the programming project about translating DNA to translate each ORF into a protein sequence.
3. In the third part, you will use the code from parts one and two together to find candidate proteins encoded by ORFs in a genomic sequence.

Start by reading through the exercise before you do anything else. That way you have a good overview of the tasks ahead. Here is a mind map of how we split the larger problem into smaller bits and how they fit together:

Finding Open Reading Frames

Find the start positions of ORFs in a DNA sequence

The first task is to write a function that finds all the possible positions where an ORF can begin.

Write a function, find_start_positions, which takes one argument:

1. A string, which is a DNA sequence.

The function must return:

- A list of integers, which represent the indexes of the first base in start codons in the DNA sequence argument.

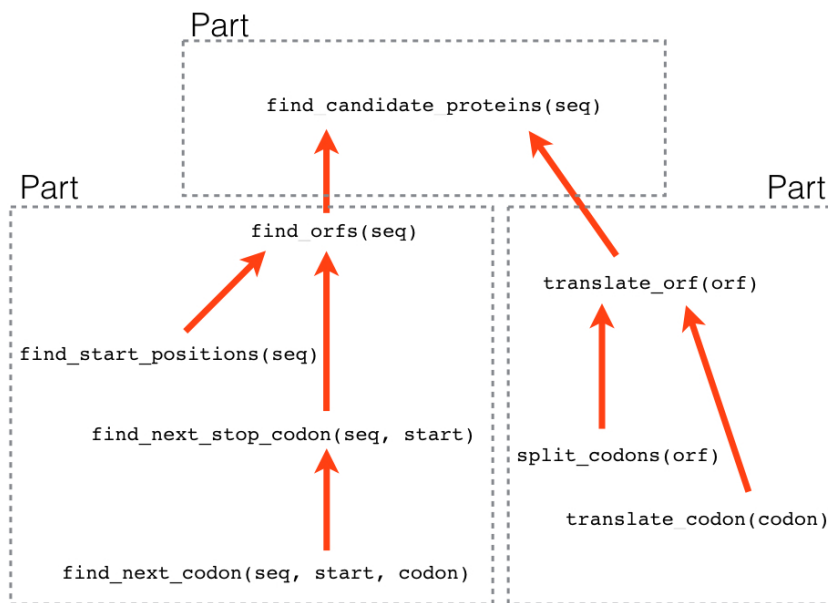


Figure 25.1: Overview

Example usage:

```
find_start_positions('TATGCATGATG')
```

should return

```
[1, 5, 8]
```

Your function should contain a for-loop that iterates over all possible positions in a DNA string where a codon can begin. Not surprisingly, these are all the positions except for the last two. So start out with this:

```
def find_start_positions(seq):  
    for i in range(len(seq) - 2):  
        print(i)
```

Now, instead of just printing *i*, try and make it print the three bases following *i* using the slicing technique:

```
triplet = seq[i:i+3]
```

I.e. if your sequence is 'TATGCATGATG' it should first print 'TAT' then 'ATG' then 'TGC' and so on.

When you have this working you should change the code so that triplets are only printed if they are start codons. You can use an if-statement that tests if each triplet is equal to `start_codon`.

Then try and make your function print *i* only when *i* is the first base of a start codon.

Finally, modify the function so all the relevant values of *i* are collected in a list using the same technique as in the `split_codons(orf)` function, and then return this list from the function.

Finding the next occurrence of some codon in an ORF

Now that you can find where the ORFs begin in our sequence you must also be able to identify where each of these end. As you know, an ORF ends at any of three different stop codons in the same reading frame as the start codon. So, starting at the start codon of the ORF, we need to be able to find the next occurrence of some specific codon. I.e. you should look at all codons after the start codon and find the first occurrence of some specified codon. If the function does not find that codon in the string it should return None.

Write a function, `find_next_codon`, that takes three arguments:

1. A string, which is the DNA sequence.
2. An integer, which is the index in the sequence where the ORF starts.
3. A string, which is the codon to find the next occurrence of.

The function must return:

- An integer, which is the index of the first base in the next in-frame occurrence of the codon. If the function does not find that codon in the string it should return None.

Example usage:

```
find_next_codon('AAAAATTTAATTTAA', 1, 'TTT')
```

should return

```
10
```

Your function should contain a for-loop that iterates over all the relevant starts of codons. Remember that no valid codon can start at the last two positions in the sequence. E.g. if the second argument is 7 and the length of the sequence is 20 then the relevant indexes are 7, 10, 13, 16.

Start by writing a function just with a for-loop that lets you print these indexes produced by range. Figure out how to make the range function iterate over the appropriate numbers.

```
def find_next_codon(seq, start, codon):  
    for idx in range( ?? ):  
        print(idx)
```

When you have that working, use the slicing technique to instead print the codons that start at each index.

Finally, add an if-statement that tests if each codon is equal to codon. When this is true, the function should return the value of idx.

Finding the first stop codon in an ORF

Now that you can find the next occurrence of any codon, you are well set up to write a function that finds the index for the beginning of the next in-frame *stop codon* in an ORF.

Write a function, `find_next_stop_codon`, that takes two arguments:

1. A string, which is the DNA sequence.
2. An integer, which is the index in the sequence where the ORF starts.

The function must return:

- An integer, which is the index of the first base in the next in-frame stop codon. If there is no in-frame stop codon in the sequence the function should return `None`.

Example usage:

```
find_next_stop_codon('AAAAATAGATGAAAA', 2)
```

should return

5

Here is some inspiration:

1. You should define a list to hold the indexes for the in-frame stop codons we find.
2. Then we loop over the three possible stop codons to find the next in-frame occurrence of each one from the start index. You can use `find_next_codon` for this. Remember that it returns `None` if it does not find any. If it does find a position you can add it to your list.
3. At the end, you should test if you have any indexes in your list.
4. If you do, you should return the smallest index in the list. I.e the ones closest to the start codon.
5. If you did not find any stop codons the function must return `None` to indicate this.

Finding ORFs

Now you can write a function that uses `find_start_positions` and `find_next_stop_codon` to extract the start and end indexes of each ORF in a genomic sequence.

Write a function, `find_orfs`, that takes one argument:

1. A string, which is a DNA sequence.

The function should return:

- A list, which contains lists with two integers. The list returned must contain a list for each ORF in the sequence argument. These lists each contain two integers. The first integer represents the start of the ORF, the second represents the end. The function should handle both uppercase and lowercase sequences.

Example usage:

```
find_orfs("AAAATGGGGTAGAATGAAATGA")
```

should return

```
[[3, 9], [13, 19]]
```

Start by using `find_start_positions` to get a list of all the start positions in sequence:

```
def find_orfs(seq):  
    start_positions = find_start_positions(seq)
```

When you have that working, add a for-loop that iterates over the start positions. Inside the for-loop, you can then get the next in-frame stop codon for each start position by calling `find_next_stop_codon`. Try to print the start and end indexes you find to make sure the code does what you think.

Finally, you need to add a `[start, stop]` list for each ORF to the big list that the function returns. To append a list to a list you do write something like this:

```
orf_coordinate_list.append([start, stop])
```

Test your function. Chances are that some of the end positions you get are `None`. This is because some of the start codons were not followed by an in-frame stop codon. Add an if-statement to your function that controls that only start-stop pairs with a valid stop coordinate are added to the list of results.

Translation of open reading frames

We need to translate the reading frames we find into the proteins they may encode. So why not use the code you already wrote in the programming project where you translated open frames? Copy the content of `translationproject.py` into `orfproject.py`. Now you can use the function `translate_orf` to translate your ORFs.

Put everything together

Read in genomic sequences

The file `e_coli_0157_H157_str_Sakai.fasta` contains the genome that we want to analyze to find open reading frames. This is an especially nasty strain of *Escherichia coli* O157:H7 isolated after a massive outbreak of infection in school children in Sakai City, Japan, associated with consumption of white radish sprouts.

You can use the function below to read the genome sequence into a string.

```
def read_genome(file_name):
    f = open(file_name, 'r')
    lines = f.readlines()
    header = lines.pop(0)
    substrings = []
    for line in lines:
        substrings.append(line.strip())
    genome = ''.join(substrings)
    f.close()
    return genome
```

Now for the grand finale: Using `read_genome`, `find_orfs` and `translate_orf` you can write a function that finds all protein sequences produced by open reading frames in the genome.

Write a function, `find_candidate_proteins`, that takes one argument:

1. A string, which is a genome DNA sequence.

The function must return

- A list of strings, which each represent a possible protein sequence.

Note that this is a full genome so finding all possible proteins will take a while (~5 min.). You can start by working on the first 1000 bases:

Example usage:

```
genome = read_genome('e_coli_0157_H157_str_Sakai.fasta')
first_1000_bases = genome[:1000]
find_candidate_proteins(first_1000_bases)
```

should return

```
['MSLCGLKKESLTAASELVTCRE*', 'MKRISTTITTTITTTITTTGNGAG*',
 'MQNVFCGLPIFWKAMPGRGRWPPSSLPPPKSPTTWWR*', 'MPGRGRWPPSSLPPPKSPTTWWR*',
 'MLYPISAMPNVFLPNF*', 'MPNVFLPNF*', 'MSCMALVC*', 'MALVC*']
```

The function should call `find_orfs` to get the list of start-end pairs. For each index pair, you must then slice the ORF out of the sequence (remember that the end index represents the first base in the stop codon), translate the ORF to protein, and add it to a list of proteins that the function can return.

Hint: To check your result note that all returned sequences should start with a start codon 'M', end with a stop codon '*' and contain no stop codons in the middle.

On your own

This is where this project ends, but *you* can continue if you like. Given a long list of candidate proteins of all sizes, what would you do to narrow down your prediction to a smaller set of very likely genes? If you have some ideas, then try them out.

- Maybe you can rank them by length? What is the expected minimum length of proteins?
- Maybe you can look for a Shine-Delgarno motif upstream of the start codon? You know how to do that from the lectures.
- You can also try to BLAST them against the proteins in Genbank. The true ones should have some homologs in other species.

26 Project: Genome assembly

This chapter is a programming project where you will assemble a small genomic sequence from a set of short sequencing reads.

In genome assembly, many short sequences (reads) from a sequencing machine are assembled into long sequences – ultimately chromosomes. This is done by ordering overlapping reads so that they together represent genomic sequences. For example given these three reads: AGGTCGTAG, CGTAGAGCTGGGAG, GGGAGGTTGAAA ordering them based on their overlap like this

```
AGGTCGTAG
  CGTAGAGCTGGGAG
    GGGAGGTTGAAA
```

produces the following genomic sequence:

```
AGGTCGTAGAGCTGGGAGGTTGAAA
```

Real genome assembly is, of course, more sophisticated than what we do here, but the idea is the same. To limit the complexity of the problem we make two simplifying assumptions:

1. There are no sequencing errors, implying that true overlaps between reads can be identified as perfectly matching overlaps.

2. No reads are nested in other reads. I.e. They are never a smaller part of another read.

The second assumption implies that overlaps are always of this type:

```
CGTAGAGCTGGGAG
      GGGAGGTTGAAA
```

and never of this type:

```
CGTAGAGCTGGGAG
      AGAGCTG
```

In this project, you will be asked to write functions that together solve the problem of assembling a genomic sequence. Each function each solve a small problem, and you may need to call these functions inside other functions, to put together solutions to larger subproblems.

On the course page you can download the files you need for this project:

- `sequencing_reads.txt` contains the sequencing reads.

You also need to download the two project files:

- `assemblyproject.py` is an empty file where you must write your code.
- `test_assemblyproject.py` is the test program that lets you test the code you write in `assemblyproject.py`.

Put the files in a folder dedicated to this project. On most computers you can right-click on the link and choose “Save file as...” or “Download linked file”.

Now open each file in your editor and have a look at what is in `sequencing_reads.txt`. (Do *not* change it in any way and do not save it after viewing. If your editor asks you if you want to save it before closing, say *no*.) How many sequences are there in each file?

The project is split into four parts:

1. Read and analyze the sequencing reads.
2. Compute the overlaps between reads.
3. Find the right order of reads.
4. Reconstruct the genomic sequence.

Here is an overview of the functions you will write in each part of the project and of which functions that are used by other functions.

Make sure you read the entire exercise and understand what you are supposed to do before you begin!

Read and analyze the sequencing reads

The first task is to read and parse the input data. The sequence reads for the mini-assembly are in the file `sequencing_reads.txt`. The first two lines of the file look like this:

```
Read1 GGCTCCCCACGGGGTACCCATAACTTGACAGTAGATCTCGTCCAGACCCCTAGC
Read2 CTTTACCCGGAAGAGCGGGACGCTGCCCTGCGCGATTCCAGGCTCCCCACGGG
```

Each line represents a read. The first field on each line is the name of the read and the second field is the read sequence itself. So for the first line `Read1` is the name and `ATGCG...` is the sequence.

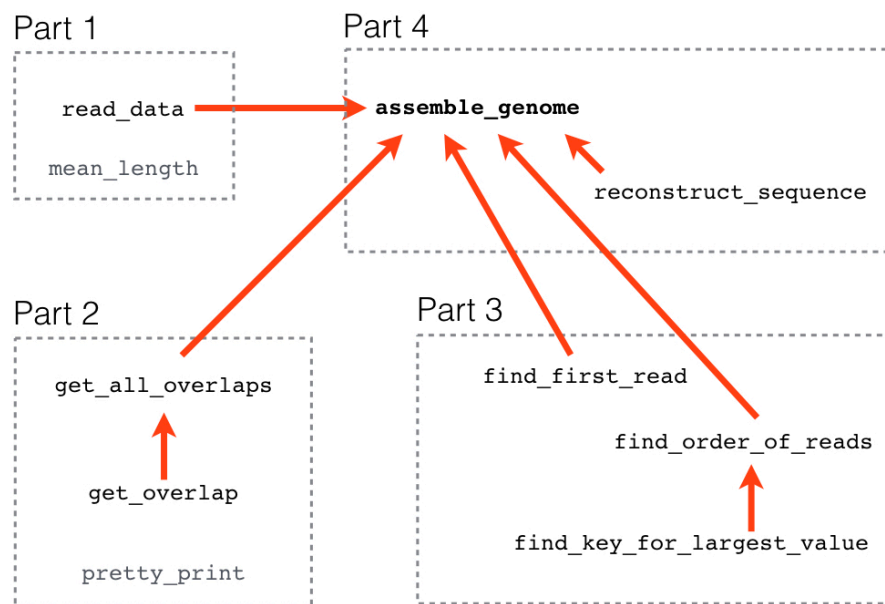


Figure 26.1: Overview

Read the sequencing reads into your program

Write a function, `read_data`, that takes one argument:

1. A string, which is the name of the data file.

The function must return

- A dictionary, where the keys are the *names* of reads and the values are the associated read *sequences*. Both keys and values must be strings.

Example usage:

```
read_data('sequencing_reads.txt')
```

should return a dictionary with the following content (maybe not with key-value pairs in that order)

```
{ 'Read1': 'GGCTCCCCACGGGGTACCCATAACTTGACAGTAGATCTCGTCCAGACCCCTAGC',
  'Read3': 'GTCTTCAGTAGAAAATTGTTTTTTTCTTCCAAGAGGTCGGAGTCGTGAACACATCAGT',
  'Read2': 'CTTTACCCGGAAGAGCGGGACGCTGCCCTGCGCGATTCCAGGCTCCCCACGGG',
  'Read5': 'CGATTCCAGGCTCCCCACGGGGTACCCATAACTTGACAGTAGATCTC',
  'Read4': 'TGCGAGGGAAGTGAAGTATTTGACCCTTTACCCGGAAGAGCG',
  'Read6': 'TGACAGTAGATCTCGTCCAGACCCCTAGCTGGTACGTCTTCAGTAGAAAATTGTTTTTTTCTTCCAAGAGGTCGGAGT' }
```

Here is some scaffold code to get you started:

```
def read_data(file_name):
    input_file = open(file_name)
    # ...
    for line in input_file:
        # ...
    # ...
```

```
input_file.close()
```

The `line` variable in the `for` loop holds each line in the file including the `\n` newline character at the end. To split each line into the name of the read and the read sequence, you can use the `split` method of strings. You can see the documentation for that method by typing `pydoc str.split` in your terminal.

Compute the mean length of reads

Having written that function we would like to get some idea about how long the reads are. More often than not there are too many reads to look at them manually, so we need to make a function that computes the mean length of the reads.

Write a function, `mean_length`, that takes one argument:

1. A dictionary, in which keys are read names and values are read sequences (this is a dictionary like that returned by `read_data`).

The function must return

- A float, which is the average length of the sequence reads.

One way to do this is to loop over the keys in the dictionary like this:

```
def mean_length(reads):  
    count = 0  
    total = 0  
    for name in reads:  
        seq = reads[name]  
        # ...
```

```
# ...  
# ...  
return total / count
```

Remember that you can use the `len` function to find the length of a read.

Compute overlaps between reads

Next thing is to figure out which reads overlap each other. To do that we need a function that takes two read sequences and computes their overlap. Remember that in the input data none of the reads are completely nested in another read.

Compute the overlap between two reads

We know that there are no sequencing errors, so in the overlap, the sequence match will be perfect. To compute the overlap between the 3' (right) end of the left read with the 5' (left) end of the right read, you need to loop over all possible overlaps honoring that one sequence is the left one and the other is the right one. In the for loop, start with the largest possible overlap (`min(len(left), len(right))`) and evaluate smaller and smaller overlaps until you find an exact match.

Write a function, `get_overlap`, that takes two arguments

1. A string, which is the left read sequence.
2. A string, which is the right read sequence.

The function must return

- A string, which is the overlapping sequence. If there is no overlap it should return an empty string.

Example usage:

```
s1 = "CGATTCCAGGCTCCCCACGGGGTACCCATAACTTGACAGTAGATCTC"  
s2 = "GGCTCCCCACGGGGTACCCATAACTTGACAGTAGATCTCGTCCAGACCCCTAGC"  
get_overlap(s1, s2)
```

should return the string

```
'GGCTCCCCACGGGGTACCCATAACTTGACAGTAGATCTC'
```

and `get_overlap(s2, s1)`

should return the string

```
'C'
```

From these two examples it seems that `s1` and `s2` overlap and that `s1` is the left one and `s2` is the right one. Treating `s2` as the left one and `s1` as the right one only gives an overlap of one base (we expect a few bases of overlap even for unrelated sequences).

Compute all read overlaps

When you have written `get_overlap` you can use it to evaluate the overlap between all pairs of reads in both left-right and right-left orientations.

Write a function, `get_all_overlaps`, that takes one argument:

1. A dictionary with read data as returned by `read_data`.

The function must return

- A dictionary of dictionaries, specifying the number of overlapping bases for a pair of reads in a specific left-right orientation. Computing the overlap of a read to itself is meaningless and must not be included. Assuming the resulting dictionary of dictionaries is called `d`, then `d['Read2']` will be a dictionary where keys are the names of reads that have an overlap with read 'Read2' when 'Read2' is put in the left position, and the values for these keys are the number of overlapping bases for those reads.

Example usage: assuming that `reads` is a dictionary returned by `read_data` then:

```
get_all_overlaps(reads)
```

should return the following dictionary of dictionaries (but not necessarily with the same ordering of the key-value pairs):

```
{'Read1': {'Read3': 0, 'Read2': 1, 'Read5': 1, 'Read4': 0, 'Read6': 29},
 'Read3': {'Read1': 0, 'Read2': 0, 'Read5': 0, 'Read4': 1, 'Read6': 1},
 'Read2': {'Read1': 13, 'Read3': 1, 'Read5': 21, 'Read4': 0, 'Read6': 0},
 'Read5': {'Read1': 39, 'Read3': 0, 'Read2': 1, 'Read4': 0, 'Read6': 14},
 'Read4': {'Read1': 1, 'Read3': 1, 'Read2': 17, 'Read5': 2, 'Read6': 0},
 'Read6': {'Read1': 0, 'Read3': 43, 'Read2': 0, 'Read5': 0, 'Read4': 1}}
```

Hint: You can use the `get_overlap` function you just made to find the overlap between a pair of reads. To generate all combinations of reads you need two for-loops. One looping over reads in left positions and another (inside the first one) looping over reads in right position. Remember that we do *not* want the overlap of a read to itself, so there should be an if-statement in the checking of the left and right reads are the same.

Print overlaps as a nice table

The dictionary returned by `get_all_overlaps` is a little messy to look at. We want to print it in a nice matrix-like format so we can better see which pairs overlap in what orientations.

This `pretty_print` function, should take one argument:

1. A dictionary of dictionaries as returned by `get_all_overlaps`.

The function should *not* return anything but must *print* a matrix exactly as shown in the example below with nicely aligned and right-justified columns. The first column must hold names of reads in left orientation. The top row holds names of reads in right orientation. Remaining cells must each hold the number of overlapping bases for a left-right read pair. The diagonal corresponds to overlaps to the read itself. You must put dashes in these cells.

Example usage: assuming that `overlaps` is a dictionary of dictionaries returned by `get_all_overlaps` then:

```
pretty_print(overlaps)
```

should print exactly

| | Read1 | Read2 | Read3 | Read4 | Read5 | Read6 |
|-------|-------|-------|-------|-------|-------|-------|
| Read1 | - | 1 | 0 | 0 | 1 | 29 |
| Read2 | 13 | - | 1 | 0 | 21 | 0 |
| Read3 | 0 | 0 | - | 1 | 0 | 1 |
| Read4 | 1 | 17 | 1 | - | 2 | 0 |
| Read5 | 39 | 1 | 0 | 0 | - | 14 |
| Read6 | 0 | 0 | 43 | 1 | 0 | - |

This function is hard to get completely right. So to spare you the frustration, this one is on me:

```
def pretty_print(d):
    print(' ', end='')
    for j in sorted(d):
        print("{: >6}".format(j), end='')
    print()
    for i in sorted(d):
        print("{: >6}".format(i), end='')
        for j in sorted(d):
            if i == j:
                s = '      -'
            else:
                s = "{: >6}".format(d[str(i)][str(j)])
            print(s, end='')
        print()
```

Make sure you understand how it works. You can look up in the documentation what "{: >6}".format(i) does.

Find the right order of reads

Now that we know how the reads overlap we can chain them together pair by pair from left to right to get the order in which they represent the genomic sequence. To do this we take the first (left-most) read and identify which read has the largest overlap to its right end. Then we take that read and find the read with the largest overlap to the right end of that - and so on until we reach the rightmost (last) read.

Find the first read

The first thing you need to do is to identify the first (leftmost) read so we know where to start. This read is identified as the one that has no significant (>2) overlaps to its left end (it only has a good overlap when positioned to the left of other reads). In the example output from `pretty_print` above the first read would be read 'Read4' because the 'Read4' column has no significant overlaps (no one larger than two).

We break the problem in two and first write a function that gets all the overlaps to the left end of a read (i.e. when it is in the right position):

Write a function, `get_left_overlaps`, that takes two arguments:

1. A dictionary of dictionaries as returned from `get_all_overlaps`.
2. A string, which represents the name of a read.

The function must return

- A sorted list of integers, which represent the overlaps of other reads to its left end.

Example usage: assuming that `overlaps` is a dictionary of dictionaries returned by `get_all_overlaps` then.

```
get_left_overlaps(overlaps, 'Read1')
```

should return

```
[0, 0, 1, 13, 39]
```

Hint: once you have made a list of left overlaps, you can use the builtin function `sorted` to make a sorted version of the list that you can return from the function.

OK, now that we have a function that can find all the overlaps to the left end of a given read, all we need to do is find the particular read that have no significant (>2) overlaps to its left end.

Write a function, `find_first_read`, that takes one argument:

1. A dictionary of dictionaries as returned from `get_all_overlaps`.

The function must return

- A string containing the name of the first read.

Example usage: assuming that `overlaps` is a dictionary of dictionaries returned by `get_all_overlaps` then.

```
find_first_read(overlaps)
```

should return

```
'Read4'
```

Find the order of reads

Now that we have the first read we can find the correct ordering of reads. We want a list of the read names in the right order.

Given the first (left) read, the next read is the one that has the largest overlap to the right end of that read. To figure out which read that is, we use our dictionary of overlaps. If the first read is 'Read4' then `overlaps['Read4']` is a dictionary of reads with overlap to the right end of read 'Read4'. So to find the name of the read with the largest overlap you must write a function that finds the key associated with the largest value in a dictionary. We do that first:

Write a function, `find_key_for_largest_value`, that takes one argument:

1. A dictionary.

The function must return the key associated with the largest value in the dictionary argument.

Having written `find_key_for_largest_value` you can use it as a tool in the function that finds the order of reads:

Write a function, `find_order_of_reads`, that takes two arguments:

1. A string, which is the name of the first (left-most) read (that returned by `find_first_read`).
2. A dictionary of dictionaries, of all overlaps (that returned by `get_all_overlaps`).

The function must return

- A list of strings, which are read names in the order in which they represent the genomic sequence.

Hints: You know the first read is given by the first argument to the function, you also know that you can find the next read in the chain of overlapping reads by using the `find_key_for_largest_value` function, and you know that you should keep adding on reads to the chain as long as the overlap is larger than two (you can use a for-loop with an if-statement inside to check that the overlap is larger than 2).

Example usage: assuming that `overlaps` is a dictionary of dictionaries returned by `get_all_overlaps` then:

```
find_order_of_reads('Read4', overlaps)
```

should return:

```
['Read4', 'Read2', 'Read5', 'Read1', 'Read6', 'Read3']
```

Make sure you understand why this is the right list of read names before you try to implement the function.

Reconstruct the genomic sequence

Now that you have the number of overlapping bases between reads and the correct order of the reads you can reconstruct the genomic sequence.

Reconstruct the genomic sequence from the reads

Write a function, `reconstruct_sequence`, that takes three arguments:

1. A list of strings, which are the names of reads in the order identified by `find_order_of_reads`.
2. A dictionary, with read data as returned from `read_data`.
3. A dictionary of dictionaries with overlaps as returned from `get_all_overlaps`.

The function must return

- A string, which is the genomic sequence.

Example usage: assuming that `order` is the list of strings returned by `find_order_of_reads`, that `reads` is the dictionary returned by `read_data` and that `overlaps` is a dictionary of dictionaries returned by `get_all_overlaps` then:

```
reconstruct_sequence(order, reads, overlaps)
```

should return one long DNA string (had to break it in three to make it fit on the page):

```
TGCGAGGGAAGTGAAGTATTTGACCCTTTACCCGGAAGAGCGGGACGCTGCCCTGCGCGATT
CCAGGCTCCCCACGGGGTACCCATAACTTGACAGTAGATCTCGTCCAGACCCCTAGCTGGTA
CGTCTTCAGTAGAAAATTGTTTTTTCTTCCAAGAGGTCGGAGTCGTGAACACATCAGT
```

Hint: iterate over the reads in order and use the overlap information to extract and join the appropriate parts of the reads.

Putting the whole thing together

Now that you have written functions to take care of each step you can write one last function that uses them to do the entire assembly.

Write a function, `assemble_genome`, that takes one argument:

1. A string, which is the name of a file with sequencing reads in the format described in the beginning of this project description.

The function must return

- A string, which is the genome assembled from the sequencing reads

Example usage:

```
assemble_genome('sequencing_reads.txt')
```

should return the assembled genome:

```
TGCGAGGGAAGTGAAGTATTTGACCCTTTACCCGGAAGAGCGGGACGCTGCCCTGCGCGATT
CCAGGCTCCCCACGGGGTACCCATAACTTGACAGTAGATCTCGTCCAGACCCCTAGCTGGTA
CGTCTTCAGTAGAAAATTGTTTTTTCTTCCAAGAGGTCGGAGTCGTGAACACATCAGT
```

Using code in other files

References

