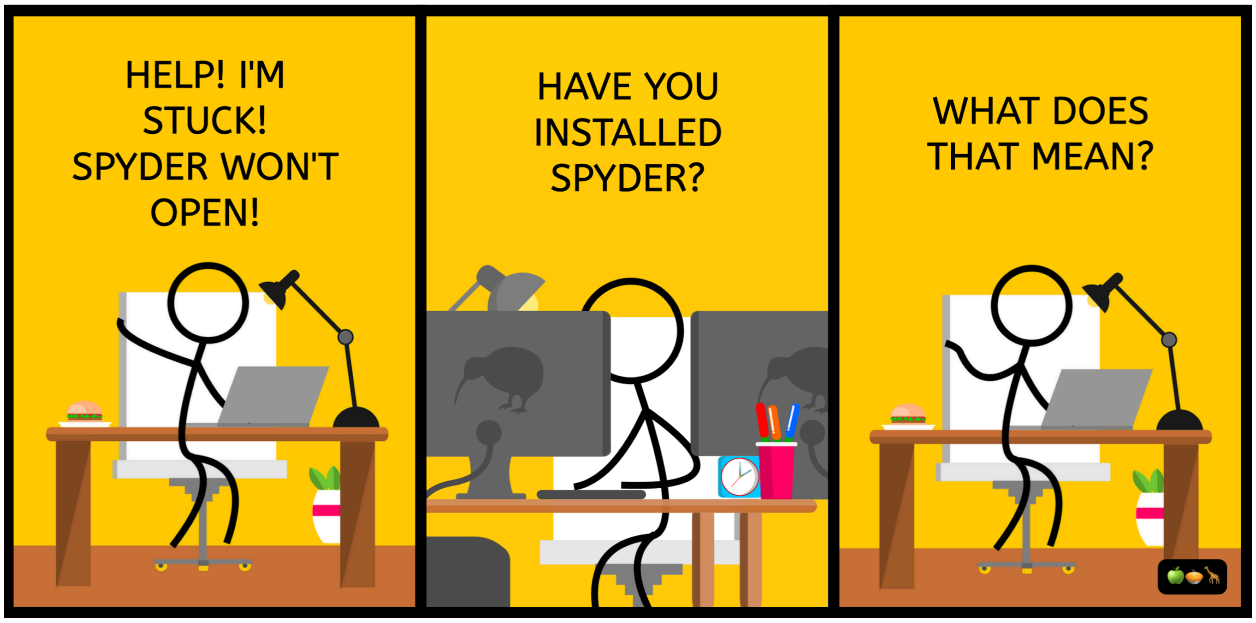
MITx 6.00.1x

Introduction to Computer Science and Programming Using Python

Lecture Videos - Notes

Table of Contents


HELP! I'M STUCK! SPYDER WON'T OPEN!
HAVE YOU INSTALLED SPYDER?
WHAT DOES THAT MEAN?

WEEK 1

Introduction

Fundamentally, computers perform calculations and store results.

Although computers are fast, if they aren't given good algorithms to work with, they wouldn't be very efficient. They would only be slow and rather unuseful.

Declarative knowledge refers to statements of fact. For instance,

- There are cookies in the jar.

Imperative knowledge is more like a recipe for how to find or figure out a fact,

- Go to the kitchen.
- Stand next to the counter.
- Open up the shelf.
- Look inside the jar.

Computers often work with imperative knowledge to help us solve problems.

An **algorithm** is a set of instructions that achieves a result (like the recipe for finding cookies in a jar). All algorithms have:

1. A sequence of simple steps.
2. A flow of control process that specifies when each step is executed.
3. A means of determining when to stop.

A **fixed program** computer is a computer that is designed to only calculate a particular program (e.g. a calculator only calculates math operations).

A **stored program** computer is a computer that is designed to load and calculate different programs (like a regular laptop computer which can do many different things).

Computers are mostly made of three things:

1. Memory, to store both data and instructions for computing things.
2. Arithmetic Logic Unit (ALU), which computes simple calculations with data stored in the computer's memory.

3. Control Unit, which keeps track of what operation the ALU should be performing at a specific moment in time (using a program counter).

Alan Turing (a great computer scientist) demonstrated that one could compute anything they wanted using a few simple operations *(move left*, *move right*, *scan*, *print*, *erase*, and *do nothing*). He also demonstrated that anything which could be computed in one programming language could also be computed in another.

The **interpreter** is a special program that executes a sequence of instructions in order and uses tests to figure out whether it should redo a current calculation, move on to the next instruction, or stop.

Every programming language can be thought of as:

1. A set of primitives (simple operations we can perform).
2. A means of combination (ways we can put those primitives together to form **expressions**).
3. A means of abstraction (ways to take an expression and treat it like a primitive).

The **syntax** of a programming language is the set of rules that defines how the code should be written.

- `8"hello"` - this line has incorrect syntax, because there's no operator between `8` and `"hello"`

- Syntax errors are rather common and easily caught.

Static semantics describes whether or not an expression with correct syntax has meaning.

- `8 + "hello"` - this is correct syntax, but you can't add an integer and a string

- Static semantic errors can keep the program from running or cause unpredictable behavior.

Semantics describes the meaning of an expression with the correct syntax. It may be what was intended, or what was not.

- `8 + 16` - correct syntax with meaning `(8 + 16 = 24)`

- Semantic errors occur when the program gives a different meaning than what the programmer intended. As the old saying goes, *Garbage in, garbage out.*

Note: There is another type of error called a **runtime error**, which is similar to a syntax error, except that it is only caught when the program is run. Syntax errors are usually caught before a program is executed.

Python Basics

A program is simply a sequence of definitions (which are evaluated) and commands (which are executed by the interpreter).

Primitives are the fundamental objects that represent data in Python**.** All objects have a **type** that determines what kinds of things programs can do with them.

Objects can either be:

1. Scalar (cannot be subdivided into smaller parts)
2. Non-scalar (have an internal structure that can be accessed)

Scalar objects in Python include:

- `int` - represent integers (e.g. 5 or 12)
- `float` - represent real numbers (e.g. 3.14 or 7.001)
- `bool` - represent either True or False values
- `NoneType` - represent only one data type, `None`

You can use the `type()` procedure to find out the type of a value (e.g `type(3)` will output `int`).

You can also use the `int()` and `float()` procedures to cast, or convert, values into each other.

- `float(3)` outputs `3.0`
- `int(3.9)` outputs `3`

Expressions are combinations of objects and operators (e.g. `<object> <operator> <object>`).

The following are common math operators in Python:

- `i+j` - the sum of `i` and `j` (as a float if `i` or `j` is a float, otherwise an integer)
- `i-j` - the difference between `i` and `j` (same as above)

- `i*j` - the product of `i` and `j` (same as above)
- `i/j` - the quotient of `i` and `j` (as a float)
- `i//j` - the quotient of `i` and `j` as an integer (remainder excluded)
- `i%j` - the remainder of the quotient of `i` and `j`
- `i**j` - `i` to the power of `j`

Python follows the order of operations (everything is read from left to right in the order they appear):

1. `()` - parentheses
2. `**` - powers
3. `*` or `/` - multiplication or division
4. `+` or `-` - addition or subtraction

A **variable** is a name associated with a value. In Python, you can create variables using the following syntax:

```
variable_name = value
```

e.g.

```
age = 16
animal = "buffalo"
is_it_raining = False
```

Variables are useful because we can easily access and reuse their values (as opposed to recalculating values every time we need it). They also make code easier to read and work with.

The equals sign (=) assigns the name on the left to the value on the right (which is stored in the memory). This process of assignment is called **binding** (since we're binding a name to a value). We can retrieve the value associated with the variable by invoking its name.

You can use the `+=` operator to increment variables:

```
radius = 4        (associate the value 4 with radius)
radius += 1       (add 1 to the value of radius)
```

You can re-bind variable names using new assignment statements:

```
animal = "buffalo"
animal = "flamingo"
```

In the above example, the old value associated with `animal` (`"buffalo"`) will be lost.

The following are common comparison operators in Python:

- `i>j` - greater than
- `i>=j` - greater than or equal to
- `i<j` - less than
- `i<=j` - less than or equal to
- `i==j` - equal to
- `i!=j` - not equal to

All of the above comparison operators will return `True` if true and `False` if false.

The following are common logic operators on booleans in Python:

- `not a` - will return the opposite of the true/false value that `a` is
- `a and b` - will return `True` only if both `a` and `b` are true
- `a or b` - will return `True` if either `a` or `b` are true

…

Another type of value is the **string**, a non-scalar value that consists of a sequence of characters such as letters, digits, or spaces.

In Python, they can be created by assigning a name to anything enclosed in single or double quotes:

```
name = 'mark'

sentence = "Let's go to the park."
```

Since strings are non-scalar, they can work with a number of different operations:

`'hello' + 'mark'` - concatenates (or adds) strings (returns `"hellomark"`)

`3 * 'mark'` - successive concatenation (returns `"markmarkmark"`)

`len('mark')` - outputs the length of, or number of characters in, "mark" (returns `4`)

`'mark'[0]` - gives the letter at the index 0 (returns "`m`")

`'mark'[1:3]` - gives all the letters starting at the index 1 up to, but not including, 3 (returns `"ar"`)

`'fantastic'[0:8:2]` - gives all the letters starting at index 0 up to, but not including 8, with a step of *two* (returns `"fnat"` since it gives every *second* character after the first one)

`str(35)` - use the `str()` function to cast other variable types into strings (returns `"35"`)

Strings are immutable, which means they cannot be modified after they have been created. In order to change a string, you would have to redefine (i.e. `my_string = my_string + "hello"`)

…

An **IDE** (integrated development environment) is a combination of (usually) a *text editor* to write, edit, and save programs, a *shell* as a place to interact with and run programs, and an *integrated debugger* to debug code.

You can use the `print()` and `input()` operators to get output and input in Python:

`print("Let's eat a cookie.")` - returns the value in the parentheses

`input("Type any letter: ")` - returns the value in the parentheses while asking for input

Conditionals

A **branching program** is a program that can run down many different ways depending on the outcome of a test. An example of this is a conditional statement. It consists of a test, a *true block* to run if the outcome of the test is true, and (optionally) a *false block* to run if the outcome of the test is false.

In Python, you can write a conditional with the `if` and `else` operators:

```
if 2 > 3:                              - a test that will either output true or false
    print("2 is greater than 3!")      - what to do if the test outputs true

else:
    print("2 is not greater than 3.")  - what to do if the test outputs false
```

Each indented set of expressions in an `if/else` clause denotes a block of instructions.

You may nest conditionals (conditionals within conditionals):

```
if 2 < 3:
    if 5 > 4:
        print(“Yay!”)
    else:
        print(“Aww!”)

elif 2 < 4:
    print(“Phew!”)

else:
    print(“Hmm.”)
```

`elif` gives the conditional another test to check if the first one outputs false. There can be multiple `elif` operators in a conditional.

`else` gives the conditional a set of instructions if all other tests output false.

`if`, `elif`, and `else` are examples of **keywords** (or *reserved words*). Python uses them to recognize the structure of a program. They cannot be used as names for variables.

The control flow then for branching programs is:

```
if <conditional>:
    <expression>

elif <conditional>:
    <expression>

...

else <conditional>:
    <expression>
```

Each conditional will output a true or false value, and the indented expressions beneath them will only run if the conditional above outputs true.

Loops

Looping programs are programs that repeat themselves until they satisfy some condition.

Using the `while` operator is an example of a looping program in Python. Their general format is:

```
while <condition>:
    <expression>
```

- The `<condition>` will evaluate either a `True` or `False` value.
- If the `<condition>` is true, the `while` loop will run the `<expression>` below it.
- The `while` loop will then check the `<condition>` again.
- It will keep running the `<expression>` beneath it until the `<condition>` is `False`.

For example:

```
n = 1

while n < 5:
    print(n)
    n = n + 1
```

The `while` loop above will keep running until `n` is not less than five.

Another type of looping program in Python is the `for` loop. It's general format is:

```
for <variable> in <expression>:

    <expression>
```

For example:

```
for n in range(5):
     print(n)
```

- The `range()` operator returns a list of values (in this case `0` to `4`).
- The first time the program goes through the `for` loop, it will treat `n` as the first value in the expression (in this case, the expression is `range(5)`).
- The program will do whatever the bottom expression says while treating `n` as the first value in the expression (which is in this case `0`).
- The next time the program runs through the `for` loop, it will treat `n` as the second value in the expression (it will do the same thing but treat `n` as, in this case, `1`).
- The program will keep doing this until it has done this for all the values in the expression.

The `<variable>` used in `for` loops is simply a placeholder for the actual values the loop will be running through the expression below.

Both `while` and `for` loops can be stopped in the midst of running with the `break` statement:

```
n = 0

for x in range(10):
    n = n + 1

    if n == 5:
        break
```

The above `for` loop will stop once `n == 5` because of the `break` statement.

`break` statements immediately exit whatever loop they are in and skip the existing remainders of code.

`while` loops versus `for` loops:

- All `for` loops can be written as `while` loops, but not all `while` loops can be written as `for` loops.
- `for` loops have a known number of iterations, while `while` loops have an unknown number of iterations.
- Both `while` and `for` loops can end early from a `break` statement.

Use the `bool()` function to determine whether things are True or False:

`bool("hello world")` - returns `True`

`bool(72)` - returns `True`

`bool(0)` - returns `False`

The general structure of `range()` is:

```
range(start, stop, step)
```

- The `start` is the start value for the `range()` function (included in output).
- The `stop` is the end value for the `range()` function (not included in output).
- The `step` is the number of values to skip between each outputted value.

For example:

`range(1, 10, 2)` - will return `1, 3, 5, 7, 9`

Iteration is the repetition of a process in order to generate a (possibly unlimited) sequence of outcomes. Each repetition of the process is a single iteration, and the outcome of each iteration is then the starting point of the next iteration. - *Wikipedia*

One characteristic of looping programs is a **loop variable**. Loop variables are:

- Initialized (created) outside of the loop.
- Changed inside the loop.
- Used in the true/false test to determine whether the loop should continue.

For example:

```
num = 5

while num <= 10:
    print(num)
    num = num + 1
```

The variable `num` in the above example is the loop variable. Loop variables are especially necessary in `while` loops, while `for` loops may use an expression to keep count of iterations.

Since strings are sequences of characters, they can be used as the expression in `for` loops:

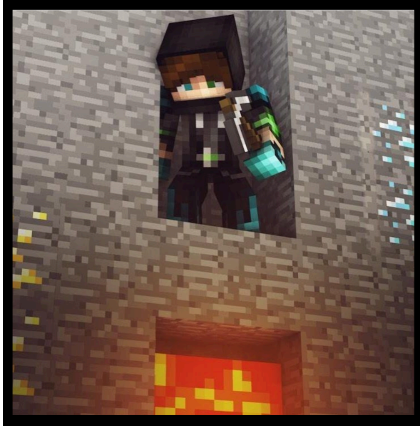
```
for letter in my_string:
    if letter == "i" or letter == "u":
        print("There is an 'i' or 'u'!")
```

Exhaustive enumeration is the process used to guess a value for a solution, check whether the solution is correct, and keep guessing until a solution is found or all possible values have been guessed. It is a type of algorithm that often implements looping programs.

Bisection search is the process used to guess a value for a solution, check whether that value is too high or too low to be correct, eliminate all other values that may be too high or too low as well, and keep guessing from the remaining values until a solution is found or all possible values have been guessed. It is a type of algorithm that often implements looping programs as well.

GOLDEN RULE OF MINECRAFT:

NEVER DIG STRAIGHT DOWN

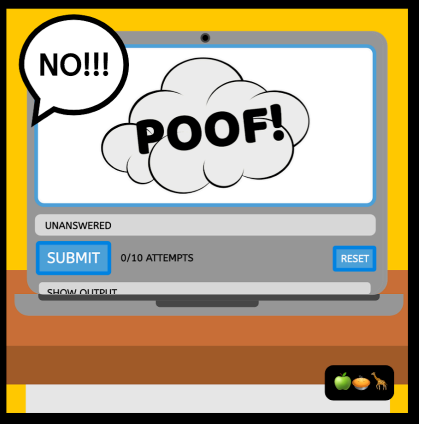


GOLDEN RULE OF LIFE:

TREAT OTHERS AS YOU WOULD WANT TO BE TREATED

GOLDEN RULE OF 6.00.1x ON edX:

ALWAYS SAVE YOUR CODE IN SOME SPARE PLACE*



WEEK 2

Binary System

Computers calculate everything using the **binary system**, a number system that uses a base of two instead of the more common base of ten. Just like numbers can be represented by the addition of powers of ten in the base ten number system, numbers can be represented by the addition of powers of two in the base two number system:

$357 = (3 * 10^2) + (5 * 10^1) + (7 * 10^0)$ - base 10 number system

$357 = 2^8 + 0^7 + 2^6 + 2^5 + 0^4 + 0^3 + 2^2 + 0^1 + 2^0$ - base 2 number system

In binary, the number shown above (357) would be written 101100101. 1s indicate the power of two is “on,” or counted, while 0s indicate the power of two is “off,” or not counted (like, 357 is 256 + 64 + 32 + 4 + 1).

Just like in the base ten number system, where numbers divided by ten have all of their digits shifted to the right by one, numbers divided by two in the base two number system do the same thing as well:

`4326 // 10 = 432` - 4326 divided by 10 is 432 (ignoring the remainder)

`10011 // 2 = 1001` - in binary, 10011 divided by 2 is 1001 (ignoring the remainder)

To represent decimals or fractions in binary, multiply the desired decimal or fraction by a power of two that will make it a whole number. Convert that whole number into binary form and then divide the binary form by the same power of two used to make the decimal or fraction a whole number:

$⅜ = 0.375 = (3 * 10^{-1}) + (7 * 10^{-2}) + (5 * 10^{-3})$

$0.375 * 2^3 = 3$ - multiply the decimal by 2^3 to make it a whole number (3)

`3 = 11` - convert 3 to binary (11)

$11/2^3 = 0.011$ - divide 11 by 2^3 (simply shift all the digits to the right three times)

Some implications of representing fractions in binary include:

- If there is no power of two that when multiplied by the fraction will make it a whole number, the binary representation of that fraction will always be an approximation.
- Because of that, it is better to avoid comparing two floats to each other with a "==," since their binary representations may not always be exactly the same. It's better to compare fractions by `abs(fraction_A - fraction_B) <= some_small_number` or some other alternative method.

Functions

- In programming, **abstraction** refers to the idea of not necessarily knowing (exactly) how something works but knowing how to properly use it instead. For example, you may not know what a module of code consists of or how it was built, but you can still use it to achieve your intended results if you know how to use it and what to use it for.

- **Decomposition** refers to the idea of breaking a problem down into smaller, self-contained pieces. For example, you may divide a very large code project into smaller, individual pieces of code that you can later combine to achieve a finished project.

Both abstraction and decomposition are important ideas that help simplify things when working with code that can easily get complicated and messy (such as in large projects).

Functions are one way to implement the ideas of abstraction and decomposition in programming. Functions are reusable pieces of code that are given a name and perform calculations with the arguments they are given.

In Python, functions are written with the keyword `def` followed by the function name and any arguments it may have in parentheses (multiple arguments are separated by commas):

```
def function_name(argument 1, argument 2):
    <expression>
```

The first line of a function ends with a colon and the following lines of a function (which consist of expressions) are indented. Arguments are the values given to functions to work with. Inside functions, arguments are known as **parameters**. Parameters serve as placeholder variables for the function to perform calculations with:

```
def add_this(number_1, number_2):
    total = number_1 + number_2
```

```
    return(total)
```

Functions are called (or **invoked**) by simply typing the function name and including any parameters it uses:

```
add_this(3, 8)
```

The above function will treat the argument `3` as the parameter `number_1` and the argument `8` as the parameter `number_2`. Since the expressions in `add_this` add those two numbers and print the result, the example above will return the value `11`.

The `return` function returns the value it is given (in this case, from a function). It differs from `print()` in that `print()` displays values while `return` returns values that can be used. For example:

```
def add_this(number_1, number_2):
    total = number_1 + number_2
    print(total)

some_variable = add_this(3, 8)
```

When the function `add_this` is called (when `some_variable` is defined), it will print `13` to the console but return the value `None` to `some_variable` (functions will return `None` if they don't contain a `return()` statement). `some_variable` will then be equal to `None` even though `add_this` added `3` and `8` printed `11`.

```
def add_this(number_1, number_2):
    total = number_1 + number_2
    return total
```

In the above example, however, when the function `add_this` is called (when `some_variable` is defined), it will not print any value but return the value `11` to `some_variable`. `some_variable` will then be equal to `11` even though `add_this` didn't print anything.

- Unlike `print()`, `return` doesn't require parentheses when called.

Also, the `return` statement can be used to return multiple values (by separating each of the additional return values with a comma):

```
return num, total, result
```

A function's **scope** describes the range of a function (what it can or can't do). Any variables or parameters that are created inside a function are **local**, which means they only exist inside the function. Once the function ends, those variables and parameters are destroyed, and cannot be called in the **global scope** (the world outside of a function, where regular variables are created). Because of this, functions can access variables outside (in the global scope), but cannot modify those variables in the global scope.

```
x = 10

def my_function(arg_1):
    x = 3
    print(x + arg_1)
    return x
```

In the above example, `x = 10` is defined in the global frame. The function `my_function` creates a local variable also named `x`, but equal to `3` instead. `my_function` prints the sum of the local variable `x` (which is 3) added to the parameter `arg_1`, and then returns the value of the local variable `x` (which is 3). Once `my_function` is finished running, calling the variable `x` will invoke the variable `x` from the global frame (which is `10`). The local variable `x` that was equal to `3` only existed within `my_function` and was destroyed once `my_function` ended.

```
x = 10

def my_function(arg_1):
    print(x)
```

The above function will print `10` if called, since no local value of `x` is defined and therefore `my_function` accesses the global variable `x`.

```
x = 10

def my_function(arg_1):
    x = x + 5
```

The above function cannot access the value of `x` in the global frame, because if so would be changing the value of the global variable `x`—something beyond the scope of a function. Since there has been no local variable named `x` that has been defined within the function, the above function will output an error.

Functions can return other functions. In such cases, the parameters for the function being returned must be included when the function is called:

```
my_function(arg1, arg2)(arg3, arg4, arg5)
```

In the above example, the second set of parentheses contains the parameters of whatever function `my_function` returns (and the returned function will take those values, use them accordingly, and output another value).

When defining functions, the arguments that a function uses can be given default values by simply assigning values to them when they are defined:

```
def my_function(arg1, arg2, arg3 = True):
    <expression>
```

A function like the one above can accept only two arguments if necessary, but will override the default value of `arg3` if it is given an additional argument.

To make code easier to read and understand, functions traditionally include a **docstring** that specifies the assumptions (the conditions that the function assumes are met in order to run) and guarantees (the conditions that the function will meet if all of its assumptions are met) of the function. Docstrings are written as multi-line comments, which are written inside two sets of three double quotes:

```
def my_function(arg1, arg2):
    """
    This is the docstring.
    It specifies the assumptions of this function…
    and the guarantees of it, too!
    """
    <expression>
```

Giving the built-in function `help()` any function name as an argument (e.g. `help(my_function)`) will display the name, arguments, and docstring of that function.

Recursion

Recursive functions are functions that call themselves. Recursion is often used in ways similar to iteration, and many calculations can often be computed using either process. However, iteration and recursion have their own pros and cons that can vary depending on the calculation being computed.

```
def factorial(number):
    if number == 0 or number == 1:
```

```
        return 1

    else:
        return number * factorial(number-1)
```

The above function uses recursion to calculate the factorial of a given number. The function `factorial` multiplies the argument `number` by the result of itself called on the difference of one less than the number until the argument `number` is equal to `1` or `0`. Because of this, the `else` clause in the function will keep running until `number` is equal to `0` or `1`. Then, `number` (which will usually be equal to `1`) will be returned to the `factorial` function that just called it (line 5), which will multiply it by `number` and return the product to the factorial function that called it (line 9), and keep repeating this process until all the `factorial` functions that have been called are satisfied.

Functions often contain a **base case** to avoid ending up in an infinite loop from calling itself too many times. A base case ensures that at some point, some value will be returned, and because of that, no more function calls will be made and all the functions that have been called will begin to be satisfied. In the above example, the base case

```
if number == 0 or number == 1:
         return number
```

ensured that the function `factorial` would begin looping back at some point (because when `number` was equal to `1` or `0` some value (usually 1) was returned and the loop will not continue endlessly.

- So in essence, recursion systematically reduces a problem (into a smaller or simpler version of that problem) until it can be solved directly and then successively returns the calculated values to the functions that called for them (in this case, `factorial` reduced the problem to a series of simple multiplications) until a final solution is returned.

Recursive functions can contain multiple base cases and more than one instance of the function in the recursive call (as seen in the following function):

```
def fibonacci(x):
    if x == 0 or x == 1:
       return 1

    else:
        return fibonacci(x-1) + fibonacci(x-2)
```

Modules

Modules are Python files that contain a collection of variables and functions. They are often used to make larger projects easier to maintain by dividing them into smaller pieces or simply to group a bunch of related variables and functions together in a single file.

To use the variables and functions in a module in another Python file (or even in the shell), use the import statement followed by the name of the desired module:

```
import math
```

To call the variables or functions from an imported module, use the name of the module followed by a period and the name of the desired variable of function:

```
math.pi
```

```
math.log(100)
```

To avoid using **dot notation** (that clunky `module.name` syntax) when using items from modules, use the `from` keyword to import the desired variables or functions:

```
from math import pi
```

```
from math import log
```

To import all the variables and functions from a module, use `*` (which is a placeholder for *all*):

```
from math import *
```

When using the above method of importing modules, be sure that none of the names of variables or functions from the module collide with any names of variables and functions in the file.

If you wish to import a module, but refer to it by a different name than it is given in your code, use the `as` keyword:

```
import math as funky
```

The name that appears after the keyword `as` is the name that the imported module will be referred to by. In the above example, after importing the module `math` as `funky`, the call `math.pi` will throw an error, but the call `funky.pi` will be perfectly fine.

If you want to open up other files to either read or write information to them, use the `open()` command in Python:

```
my_file = open("some_file", "w")
```

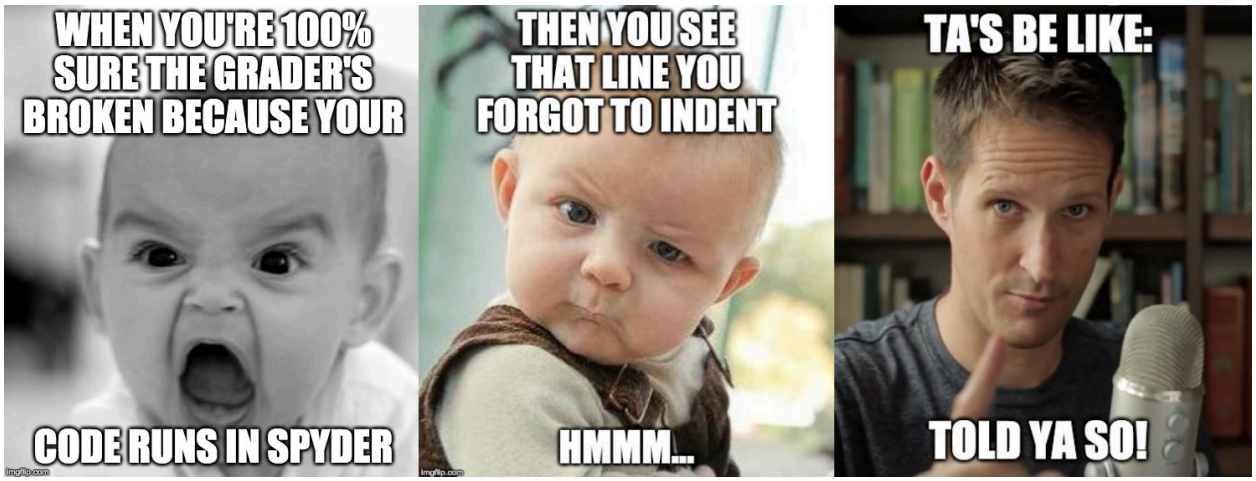
The first argument `open()` takes is the name of the file you want to open and the second argument indicates what you want to do with that file (in this case, `"w"` means the file is opened to write information to it). In the above example, the variable `my_file` is assigned to a file named `some_file`.

You can use the `.write()` function to write information to a file or the `.close()` function to close a file when you're finished:

```
my_file.write("Hello, there!" + "\n")

my_file.close()
```

You can open a file to read (by using `"r"` instead of `"w"` as the second argument) to read information in the file:

```
for line in my_file:

    print(line)
```



WEEK 3

Data Structures

Tuples are a type of data structure in Python that consist of an ordered sequence of elements. A single tuple can contain different types of elements (such as integers, strings, or even other tuples). Tuples are **immutable**, which means like strings, values within tuples can be accessed but not modified.

In Python, tuples are created by assigning a tuple name to a series of items (separated by commas) enclosed in parentheses:

```
my_tuple = (“buffalo”, 8, 3.6, “hello”)
```

Elements in tuples can be accessed by indexing or sliced by… slicing:

`my_tuple[0]` - returns `“buffalo”`

`my_tuple[1:3]` - returns `8, 3.6`

To create a tuple with a single element, include a comma after the element (to avoid confusing the parentheses with order of operations or something):

```
other_tuple = (“flamingo”,)
```

```
other_tuple = “flamingo” # parentheses are optional
```

Or to create an empty tuple:

```
empty_tuple = ()
```

Tuples are iterable (just like strings):

```
for x in my_tuple:

    print(x)
```

Tuples can be assigned to each other:

```
other_tuple = my_tuple
```

```
(x, y) = (y, x)
```

Use the following syntax to access elements within tuples (or characters within strings) within tuples:

```
a_tuple = (2, 3, "hello", (9, "eight", "hi"), 17.2)
```

`a_tuple[3][0]` - returns the element at position `0` in the element at position `3`

The above case would return `9`.

Lists are another type of data structure in Python that also consists of an ordered sequence of elements and can be internally accessed by indexing. The difference between lists and tuples is that lists are **mutable**, which means the elements inside them can be modified. A single list can contain multiple object types (although this is often uncommon) such as strings, integers, floats, or even other lists or functions.

In Python, lists are created by assigning a list name to a series of items (separated by commas) enclosed in brackets:

```
my_list = ["flamingo", 18, "bye", 2, 1]
```

Like tuples, lists are iterable and can be assigned to each other. Individual elements of a list can be modified using the following syntax:

```
my_list[2] = "see you tomorrow"
```

The above example changes in the element at position `2` (`"bye"`) in the list `my_list` to `"see you tomorrow"`.

Both tuples and lists can be concatenated (i.e., added to each other):

```
new_tuple = my_tuple + other_tuple
```

```
new_list = my_list + some_list
```

And multiplied:

```
my_tuple * 3
```

```
my_list * 8
```

The keywords `in` and `not` can be used to check for whether certain elements are in a tuple or list:

```
"Hello" in my_tuple     # will return 'True' if so (otherwise,
'False')

3 not in my_list      # will return 'True' if so (otherwise, 'False')
```

The `len()` function is useful for getting the *length* of a string, tuple, or list:

`len("wonderful")` - returns `9`

`len(my_tuple)` - returns `4` (from the above example)

The `.append()` function is useful for adding elements to the end of a list:

```
my_list.append("happier")
```

The above example adds the elements `"happier"` to the list `my_list`.

The `.extend()` function is useful for adding lists or tuples (or groups of elements) to lists:

```
my_list.extend((2, 3))
```

The above example adds two elements, `2` and `3`, to the list `my_list`.

The `.insert()` function is useful for adding an element in a specific index in a list:

```
my_list.insert(2, "mountain")
```

The above example inserts the string `"mountain"` to the index `2` in the list `my_list`.

The `.remove()` function is useful for removing specific elements from a list:

```
my_list.remove("flamingo")
```

The above example removes the first instance of the string `"flamingo"` in the list `my_list`.

The `del` function is useful for removing elements at certain indexes in a list:

```
del(my_list[2])
```

The above example removes the element at position `2` in the list `my_list`.

The `.pop()` function is useful for simultaneously removing and returning the last element of a list:

```
my_list.pop()
```

To pop an element at a specific place in a list, include the index of the desired element in parentheses of `.pop()`:

```
this_list.pop(5)
```

The above example removes and returns the element at index `5` of the list `this_list`.

The `list()` function is useful for converting a string into a list (with each character of the string a separate item of the list).

```
list("wonderful")
```

The above example would return `["w", "o", "n", "d", "e", "r", "f", "u", "l"]`.

The `.split()` function is similar to the `list()` function in that it converts string into a list except that it splits the characters in the string to make the elements in the list based on the character it is given:

```
s = "wonderful"

s.split("e")
```

The above example would split the string `s` into individual elements in a list whenever the character `"e"` is found (i.e. returning `["wond", "rful"]`.

The `"".join()` function is useful for joining elements in lists into strings:

```
another_list = ["hey", "what", "wow"]

"".join(another_list)
```

The above example returns `"heywhatwow"`.

To insert characters between each element of a list when using the `"".join()` function, simply include the desired characters in parentheses:

```
"_".join(another_list)
```

The above example returns `"hey_what_wow"`.

The `sorted()` function is useful for returning a sorted version of a list without changing the list itself:

```
sorted(my_list)
```

The `.sort()` is the same as the `sorted()` function except that it actually changes the list itself:

```
my_list.sort()
```

The `reverse()` function is useful for reversing the order of the elements in a list:

```
my_list.reverse()
```

Use the `.count()` function to count the number of times elements appear in a list:

```
this_list.count(4)
```

The above example returns the number of times `4` occurs as an element in `this_list`.

The `.index()` function is useful for returning the index of an element in a list:

```
this_list.index("hello")
```

The above example returns the index of the first instance of the element `"hello"` in the list `this_list`.

Note: when called, the `range()` function actually just returns (or, more technically, yields) a tuple of numbers.

Aliasing is the term used to describe multiple variables that point to the same list:

```
colors = ["orange", "green", "purple"]

more_colors = colors
```

In the above example, `colors` and `more_colors` are aliases of each other since they both point to the same list. Changing this list using one variable (say, `more_colors`) will change the

same list accessed by the other variable (in this case `colors`), which can occasionally complicate things.

To avoid aliasing, **clone** lists instead of assign other variable names to them:

```
other_colors = colors[:]

some_colors = [“orange”, “green”, “purple”]
```

Use the `==` comparison operator to check whether lists are equal to each other:

```
colors == some_colors     # will return ‘True’
```

Use the `is` keyword to check whether two variable names point to the same list:

```
colors is some_colors     # will return ‘False’
```

In the above example, unique lists are created and there are no variables pointing to the same list.

- When iterating over lists, it is usually a good practice to avoid mutating the list while still in the process of iteration, since adding or removing elements to a list changes the indexes of the elements in the list and can potentially lead to problems such as counting errors.

- One method of avoiding this problem is by cloning a list and iterating over the cloned list while changing the original (ensuring that the list being used by the iteration does not change while the list not being used by the iteration gets mutated).

The `map()` function behaves like the `range()` function in that it yields an iterable set of values. `map()` takes a function and applies it to every element in one or more lists:

```
L1 = [1, -2, 5, -3, -4, 8, -7, 11]

for x in map(abs, L1):

    print(x)
```

The above example would print every element of the list `L1` with the `abs()` function applied to it (returning `1`, `2`, `5`, `3`, `4`, `8`, `7`, and `11`).

(The `abs()` function returns the absolute value of an integer or float (i.e. `abs(-3)`).)

Lists can be indexed using indexes from other lists. See the following example:

```
a = [1, 2, 3, 4, 0]
b = [3, 0, 2, 4, 1]
c = [3, 2, 4, 1, 5]

a[a[1]]
a[b[2]]
a[c[a[b[0]]]]
a[c[a[b[3]]]]
```

The above indexes on the lists `a`, `b`, and `c` would be equal to `3`, `3`, (the third index would actually end up as an IndexError), and `4`, respectively.

…

Dictionaries are another type of data structure found in Python. They are similar to lists in that they are mutable and can handle different types of elements. They are different, however, in that they store pairs of data (or in other words, allow customizable indexes).

Dictionaries are created using the following syntax:

```
dictionary_name = {key: value, key: value, … }

my_dictionary = {“Mark”: “A”, “Linda”: “B”, “Aaron”: “A+”}
```

Access values stored in dictionaries by using the key associated with that value:

`dictionary_name[key]` - returns the value associated with the given key

`my_dictionary[“Linda”]` - returns `“B”`

Add values to a dictionary using the following syntax:

```
dictionary_name[key] = value

my_dictionary[“Stacy”] = “A”
```

- adds entry to the end of `my_dictionary`

Check if values are in a dictionary using the following syntax:

`key in dictionary_name` - returns a boolean value

`"Mark" in my_dictionary` - returns `True`

Use the `del` keyword to delete entries in dictionary:

`del dictionary_name[key]` - deletes entry at associated key

```
del my_dictionary["Stacy"]
```

Use the `.keys()` and `.values()` functions to return a tuple of all the keys or values of a dictionary:

```
my_dictionary.keys()

my_dictionary.values()
```

Use the `.get()` function to "safely" access the values of keys in a dictionary. If in the event the desired key is not in the dictionary, the `.get()` operator will not throw an error but rather return its second argument:

```
my_dictionary.get("a", "Key not found!")
```

In dictionaries, values can be both mutable and immutable, ranging from anything such as integers to strings to functions and even other dictionaries. Values can also be duplicates.

Use the `.copy()` function to return a copy of a dictionary:

```
another_dictionary = my_dictionary.copy()
```

In dictionaries, keys have to be unique and can only be immutable (more accurately *hashable*) types such as strings or tuples. A single dictionary can contain various types of keys in any particular order.

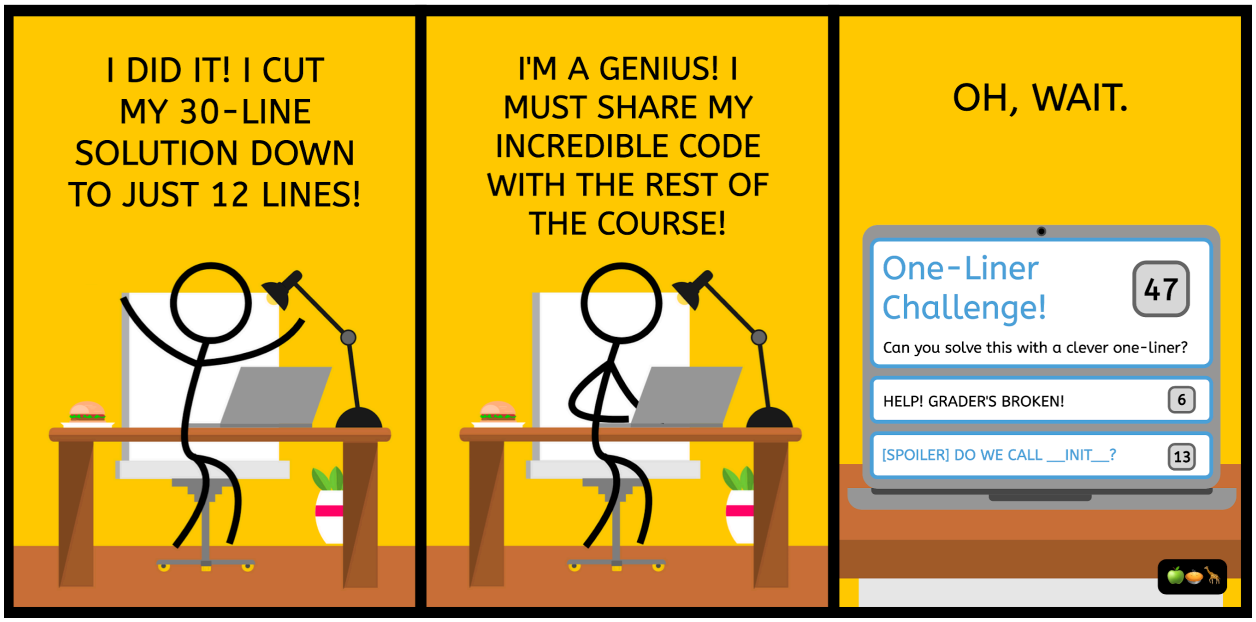
The `global` keyword is useful for creating variables within functions that can be accessed outside the scope of those functions:

```
def a_function:
    global count
    count = 0

    for x in range(10):

        count += 1
```

```
print(count)
```

In the above example, the variable `count` can be accessed out of the function `a_function` since it was declared as a global variable.

Although global variables are helpful in some instances, they are generally avoided unless they are necessary or particularly helpful because they can easily complicate things.



WEEK 4

Debugging

Debugging is the process of finding and removing mistakes (or, “bugs”) in code. There are various ways to go about debugging, such as by studying the events that led up to an error, purposely attempting to “break” a program in order to identify potential weaknesses, or by simply practicing **defensive programming** to make debugging easier in the first place.

Defensive programming is writing code in such a way as to make debugging easier and less complicated. Common practices in defensive programming include including docstrings when writing functions, breaking down projects into modules, and specifying the expected inputs, outputs, and results of modules.

There are several different types of testing when looking for bugs in code:

- **Unit testing** is making sure each component of a program works correctly by individually testing each function or module of a project.
- **Regression testing** is rechecking a piece of code after fixing a bug to ensure that the bug has been fixed and no additional bugs have been introduced in the process.
- **Integration testing** is making sure the entire program works as a whole by testing the entire program (as opposed to unit testing).
- **Black box testing** is an approach to testing that doesn’t require knowledge of how the function being tested was written. Rather, it is checking the function using different test cases based on the expected input(s), output(s), and result(s) of the function (natural partitions).
- **Glass box testing** is an approach to testing that checks a function by using different test cases based on how the function was written. It attempts to use as many test cases as necessary to check every potential path of the function (such as by exercising each branch of a conditional or running multiple variations of a loop in a function). Testing every potential path of a function may not always be possible, however, such as is the case with recursive functions, which may have a wide range of potential paths.

Natural partitions are test cases that intuitively check a function for different test cases based on what the function does. For instance, the natural partitions for a function that calculates the

absolute values of integers may be: 0, 1, n < 0, n > 0 (which are test cases designed to check the functionality of a function).

If no natural partitions are known, **random testing** (simply providing random inputs to check a function) may be used instead.

There are several different types of bugs in programming:

- **Overt bugs** are bugs that have obvious manifestations, such as in code that crashes or runs forever. They are often relatively easy to spot.
- **Covert bugs** are bugs that don't have obvious manifestations, such as in a value being returned by a program, but that value sometimes (or always) being incorrect. They can be more difficult to find than overt bugs.
- **Persistent bugs** appear every time code is run.
- **Intermittent bugs** appear sometimes when code is run, even when the inputs of the code are the same. They can be difficult to find but are catchable if the exact same conditions used to run the code are reproduced.

Some tips for finding bugs include:

- Use `print()` statements throughout a function to print out arguments, values, or results to understand what's happening at every step of execution and pinpoint where your program may be going wrong.
- Use the error messages in the console to figure what type(s) of error(s) have occurred (i.e. `TypeError`(s), `IndexError`(s), `NameError`(s), etc.) and where they are located.
- In order to understand your own thought process and what's going on in your code, imagine you are explaining the code to someone else.
- Rather than asking yourself, "What's wrong with my code?" ask yourself, "How did I get this result?".
- Save backup versions of your code before making changes while debugging to avoid messing things up and not being able to get back to your original code.

Exception Handling

Exception (or error) **handling** is the process of instructing a computer in what to do when an error occurs. By default, Python displays an error message and stops running when an error occurs, but this default behavior can be changed using a few keywords.

In Python, you can handle exceptions with the keywords `try` and `except`:

```
try:
    num = int(input("Give me a number: "))
    print("Your number was " + str(num))

except:
    print("Oh no! An error has occurred!")
```

Everything within the body of the `try` statement is executed until an error occurs, at which point Python skips down and executes the `except` clause instead of displaying an error message and terminating the program. If no error occurs, the `try` clause is run, the `except` clause is skipped, and the program runs as normal.

To include specific instructions for different cases or types of errors, use the `except` operator followed by the name of the error you want to handle (i.e. `ValueError`):

```
try:
    num = int(input("Enter a number: "))
    print("Your number was " + str(num))
    print("Half of that is " + str(num/2))

except ValueError:
    print("Sorry! A value error has occurred!")

except TypeError:
    print("Sorry! A type error has occurred!")

except:
    print("Oh no! An error has occurred!")
```

Each of the `except` clauses are run if the error they handle occurs. If any other error occurs, the last `except` clause (unspecified) is run. If no error(s) occur, the `try` clause is run and all the other `except` clauses are skipped.

There are several common types of errors in Python:

- `SyntaxError`: this type of error occurs when Python cannot parse (read) a program due to errors in the program's syntax.
- `NameError`: this type of error occurs when the local or global name of an object cannot be found
- `AttributeError`: this type of error occurs when a reference to an attribute fails
- `TypeError`: this type of error occurs when an operator isn't given a correct operand
- `ValueError`: this type of error occurs when an operator is given the correct operand, but the value of the operand is inappropriate

- `IOError`: this type of error occurs when the input/output system reports an error (such as being unable to locate or open a file)

The keyword `else` can be used to execute code after a `try` clause runs with no errors:

```
try:
    greeting = input("Enter a greeting: ")
    print(greeting)

except:
    print("Oops! An error has occurred.")

else:
    print("Greeting successful!")
```

The `finally` clause executes code at the end of a `try` statement, regardless of whether or not any errors have occurred or `break`, `continue`, or `return` statements have been executed within the `try` statement:

```
try:
    greeting = input("Enter a greeting: ")
    print(greeting)

except:
    print("Oops! An error has occurred.")

else:
    print("Greeting successful!")

finally:
    print("Greeting or not, welcome to Cloud Cuckoo Land!")
```

The `finally` clause is useful for executing instructions that you wish to be run no matter what happens.

Use the `raise` operator to raise exceptions (including custom exceptions) on your own:

```
try:
    num = int(input("Enter a number: "))
    print("Your number was " + str(num))
    print("Half of that is " + str(num/2))

except ValueError:
```

```
    print("Sorry! A value error has occurred!")

except:
    raise TypeError("Oh no! A type error has occurred!")
```

The `raise` operator raises whatever error is typed after it (in this case, `TypeError`) plus a custom display message (in this case, `"Oh no! A type error has occurred!"`).

All these exception handling operators can be used (and are quite useful) in functions.

...

The `assert` operator is another exception handling operator that exemplifies defensive programming quite well. The `assert` operator executes code and terminates a function if specified assumptions are not met.

```
def divide_data(some_data):
    assert len(some_data) > 0, "Oh no! No data received!"
    return some_data / data
```

In the above example, the `assert` statement "assumes" that the length of `some_data` is longer than `0`; if in the event this is not the case, the `assert` statement will raise an `AssertionError` and output, `"Oh no! No data received!"`, terminating the function (and therefore skipping the return statement).

Although they can be used elsewhere, `assert` statements are usually used to check the inputs of functions. They are useful for catching bugs and checking values for legality.


YOU WHEN THINK YOU'RE SMART WITH BASIC PYTHON SKILLS
THEN YOU SEE YOUR FIRST
LIST COMPREHENSION
NOW THERE'S NO GOING BACK
LIST COMP
EVER

WEEK 5

Classes

---

*"Python is an [**object-oriented programming language**]. Object-oriented programming (OOP) focuses on creating reusable patterns of code, in contrast to procedural programming, which focuses on explicit sequenced instructions. When working on complex programs in particular, object-oriented programming lets you reuse code and write code that is more readable, which in turn makes it more maintainable."*

- *How To Code in Python 3 by Lisa Tagliaferri*

Object-oriented programming makes code easier to read, organize, and manage by increasing modularity in programming.

As we've seen already, Python supports several different types of data. Each instance of these types of data is known as an object and possesses a type (such as an integer, float, string, etc.), an internal representation in the computer (the means by which they are stored in the computer's memory), and a set of procedures for interaction with object (such as operators or methods). Objects can be created and destroyed in Python.

Besides the types of objects already built-in to Python, you can create your own object types by using **classes**. After creating a class by defining its name and attributes, you can use that class by creating *instances* of objects from the class and performing operations on them. Classes make it easy to reuse and organize code by grouping objects that share both common attributes and procedures that operate on them.

To create a class in Python, use the `class` keyword followed by the name of your class and the name of the parent class in parentheses followed by a colon. By convention (tradition), class names are always capitalized in Python:

```
class Animal(object):

    <body>
```

In the above example, the class `object` is used as the parent class to establish `Animal` as an object in Python and inherit all of the parent class `object`'s attributes. `object` is known as a superclass of `Animal` (more on this later).

The body of a class contains the **attributes** of the class. Data attributes are objects that make up the class. Procedural attributes (called **methods**) are functions that are designed specifically

to work on objects of the class. The first function (or method) in a class is a special function (called `__init__`) that specifies how to create a new instance of the class:

```
class Animal(object):
    def __init__(self, size, color, mood):
        self.size = size
        self.color = color
        self.mood = mood
        self.alive = True
```

The first parameter of the function `__init__` is (by convention) always called `self`. It serves as a way to reference an instance of the class when an instance is created. The following parameters (in this case, `size`, `color`, and `mood`) are data attributes of every instance of the class that will be created (e.g. when an instance of the class is created, it will possess its own version of each one of these attributes).

The body of the function `__init__` usually consists of statements that bind the parameters passed to `__init__` (in this case, any values passed for `size`, `color`, and `mood`) to the instance of the class when an instance of the class is created. The dot notation locally binds a particular attribute of the instance of the class with a desired attribute. As seen in the above example, not all attributes need to be bound to a parameter from `__init__` (as is the case with the attribute `alive` being passed a default value of `True`).

To create a new instance of a class, type the name of the instance followed by the assignment operator and the name of the class of which you want your instance to be part of. After the name of the class, provide values for all the parameters in the `__init__` function of that class (in parentheses).

```
hippo = Animals("large", "purple", "amused")
```

There is no need for the parameter `self` to be passed a value because it automatically references the instance being created (in this case, the parameter `self` would refer to the instance `hippo`).

You can access particular attributes of an instance of a class by using dot notation:

```
hippo.size
```

The above example would return `"large"` because the `__init__` function bound the parameter `size` to the attribute `size` for the instance `hippo`. The statement `self.size = size` in `__init__` would have become `hippo.size = "large"` when the instance `hippo` was created.

Whenever a new instance of a class is created, a new scope, or **frame**, is created (similar to the way functions have their own scope) in which all the attributes of that new instance are bound. When the call `hippo.size` is made (as in the above example), Python looks up the frame `hippo` and finds the value associated with `size` (in this case, `"large"`) in it. In this way, there are no errors when multiple instances of a class are created and multiple attributes with the same name created as well.

Additional procedures, or methods, can be created to work the attributes of instances of a class. Methods are limited to the scope of the class in which they are created, thereby also allowing multiple methods with the same names to be created and used in different classes. By default, Python automatically passes a value for the parameter `self` every time a method call is made, which is why `self` is often the first parameter of every method of a class:

```
class Animal(object):
    def __init__(self, size, color, mood):
        self.size = size
        self.color = color
        self.mood = mood
        self.alive = True

    def feeling(self):
        return "The", self.color, str(self), "is feeling", self.mood,
               "."

    def colors(self, other):
        return "The", str(self), "is", self.color, "and the",
               str(other), "is", other.color, "."
```

In the above example, the function `feeling` uses dot notation to access the attributes of whatever instance is passed for the parameter `self`. Method calls are made using dot notation as well:

```
print(hippo.feeling())
```

A method call is made by typing the name of the instance followed by a dot and the name of the desired method along with any additional arguments (in parentheses). In the above example, the method `feeling` only takes one argument, `self`, which is automatically passed by Python so no additional arguments are needed. The above example would print, `"The purple hippo is feeling amused."`.

Alternatively, methods can be called by typing the name of the class followed by a dot and the name of the method will *all* the arguments it takes (in parentheses):

```
print(Animals.feeling(hippo))
```

However, using this method will require you to provide an argument for `self` since the method being called will need to know what instance to work on.

```
giraffe = Animals("large", "yellow", "mellow")

print(hippo.colors(giraffe))
```

The above example exemplifies a method call with an additional argument and would print, `"The hippo is purple and the giraffe is yellow."`.

There are several (in fact, many) built-in methods that Python uses when function calls are made on instances of classes. For example, when called on an instance of a class, the `print()` function uses a method named `__str__`:

```
print(hippo)
```

The above call would print something such as `<__main__.Animals object at 0x7fa918510488>`. To change the way `print()` behaves on instances of the class `Animal`, we can redefine `__str__` within `Animal` to do what we want:

```
class Animal(object):
    def __init__(self, size, color, mood):
        self.size = size
        self.color = color
        self.mood = mood
        self.alive = True

    def feeling(self):
        return "The", self.color, str(self), "is feeling", self.mood,
               "."

    def colors(self, other):
        return "The", str(self), "is", self.color, "and the",
               str(other), "is", other.color, "."

    def __str__(self):
        return "< A", str(self), "is an animal! >"
```

Calling the `print()` function on an instance of the class `Animal` (say, `hippo`) will now print:

```
< A hippo is an animal! >
```

Other built-in methods which can be redefined include the `__add__` and `__eq__` methods, which change the way the `+` and `==` operators work, respectively. For example, adding the following code to the end our `Animal` function will change the way expressions such as `hippo + giraffe` or `hippo == giraffe` are run:

```
def __add__(self, other):
        return "What do you get when you cross a", str(self), "with
                a", str(other) + "?"

def __eq__(self, other):
        return "What's the difference between a", str(self), "and
                a(n)", str(other) + "?"
```

When creating classes, it is helpful to remember what objects consist of. The name of the class specifies the *type* of the object being created, the `__init__` function specifies the way objects of that class are *internally represented*, and the rest of the functions specify the way objects of that type can be *interacted* with. Classes are *types* while their instances are *objects* of those types. Typically, the functions in a class are operations specially designed to meet the needs and specifications of objects of that class.

When creating classes, it is generally a good practice to avoid directly manipulating attributes of an instance of that class (such as by using dot notation to directly access and change attributes (e.g. `hippo.color = "purplish-brown"`)). Instead, it is better to include separate functions in the class that return the values of certain attributes (known as **getters**) and other functions that change the values of certain attributes (known as **setters**). This is to ensure that there is no confusion when accessing or changing the values of attributes (especially in large, complex classes where multiple values may depend on each other) and to make things less complicated for other people who may use your class (e.g. other programmers need not know how you created your class, only how to use the functions within it (a form of abstraction)).

```
class Rectangle(object):
    def __init__(self, length, width):
        self.l = length
        self.w = width
        self.area = length * width

    def getLength(self):
        return self.l

    def getWidth(self):
        return self.w
```

```
    def getArea(self):
        return self.area

    def setLength(self, newLength):
        self.l = newLength
        self.area = self.l * self.w

    def setWidth(self, newWidth):
        self.w = newWidth
        self.area = self.l * self.w
```

In the above example, the various functions after `__init__` ensure that the attributes of any instance of `Rectangle` can be accessed and updated efficiently. In the case of `setLength` and `setWidth`, the attribute `self.area` is updated appropriately along with `newLength` or `newWidth`.

Classes can be used to create **hierarchies**, or groups of **parent classes** (also called superclasses) and **child classes** (also called subclasses). A subclass is a class that inherits all of the attributes and methods of its associated superclass. It may contain new attributes or methods, use existing attributes or methods from its parent class, or redefine existing attributes or methods from its parent class to suit its own needs.

The name (in parentheses) after the name of a class is the name of the parent class from which that class inherits. In most cases, the first class in a hierarchy is set to inherit from the class `object`, a built-in class from Python which contains a number of basic methods (such as `__init__` and `__str__`). The rest of the classes in a hierarchy typically inherit from each other:

```
class Dog(Animal):
    def sound(self):
        return "Bark!"

    def action(self):
        return "The dog rolled over."

    def __str__(self):
        return "< A", str(self), "is a dog! >"
```

In the above example, the class `Dog` is created as a subclass of the class `Animal`. There is no `__init__` method because the class `Dog` can inherit that method from the class `Animal`, but there are two new methods (`sound` and `action`) and an existing method from the class `Animal` (`__str__`). The two new methods can be used on any instance of the class `Dog`, and

so can any methods included in the class `Animal` (such as `feeling` or `colors`). The `__str__` method, being redefined, will now only return `"A <self> is a dog!"` if called on an instance of the class dog. To access the original `__str__` method from the class `Animal`, use the following syntax:

```
Animal.__str__(<instance>)
```

The dot notation specifies which method from which class is to be used, and `<instance>` is the name of the instance you want the method to be called on.

An instance of the class `Dog` can now be created:

```
retriever = Dog("medium", "golden-brown", "excited")
```

And worked with:

```
print(retriever.action())

print(retriever.feeling())
```

The above examples would print `"The dog rolled over."` and `"The golden-brown retriever is feeling excited."`.

When a method is called on an instance of a class in a hierarchy, Python goes into the class being called and searches for the method being called. If no method is found, Python goes into the next class in the hierarchy (the parent class) and searches for the method there. Python continues doing this until the desired method is found. In cases where multiple classes in a hierarchy contain methods with the same names, the first method found is the one used. Classes cannot access methods in classes below them in a hierarchy.

```
class Predator(Animal):
    def __init__(self, size, color, mood, prey, hungry):
        Animal.__init__(self, size, color, mood)
        self.prey = prey
        self.hungry = True

    def eat(self):
        return str(self) + "s eat", prey + "s."

    def __str__(self):
        return "< A", str(self), "is a predator! >"
```

In the above example, the class `Predator` calls on the `__init__` method from the parent class `Animal` to initiate an instance of itself. The `__init__` method from the class `Animal` runs with the parameters passed to it (`size`, `color`, `mood`), and the additional attributes `prey` and `hungry` are created for the class `Predator`.

```
class Wolf(Predator):
    def sound(self):
        return "Howl!"

    def action(self):
        return "The wolf growled."

    def __str__(self):
        return "< A", str(self), "is a wolf! >"
```

In the above example, the class `Wolf` is a subclass of the class `Predator`, which is a subclass of the class `Animal`. Any instance of the class `Wolf` will have access to the methods in the classes `Wolf`, `Predator`, and `Animal`.

You can create subclasses that have more than one parent class by including the names of additional classes (separated by commas) in parentheses after the class name. In this case, Python will search for attributes or methods through the parent classes (and their respective hierarchies) from left to right:

```
class C(A, B):
    def __init__(self):
        self.etc = "etcetera"
```

In the above example, Python would search for attributes or methods by looking through the class `A` and all the classes above it in its hierarchy before moving onto `B` and all the classes above it in its hierarchy.

Besides just defining instance variables (or, attributes) in classes, you can create class variables that exist within classes but outside methods. These can be useful when you want to create variables that are part of a class that aren't limited to the scope of any method within the class.

```
class Lemming(Animal):
    number = 1
    def __init__(self, size, color, mood)
        Animal.__init__(self, size, color, mood)
        self.ID = Lemming.number
        number += 1
```

```
    def sound(self):
        return "Meep!"

    def __str__(self):
        return "< A", str(self), "is a lemming! >"
```

In the above example, the class variable `number` is created by simply being defined outside a method (and conventionally, before `__init__`). Class variables can be accessed by typing the name of a class followed by a dot and the name of the class variable (in this case, `Lemming.number`). In the above example, whenever the `__init__` function is run (when an instance of `Lemming` is created), the `__init__` method from the class `Animal` is called, the attribute `ID` is bound to the current value of the class variable `number`, and `number` is incremented by `1`. In this way, every time a new instance of `Lemming` is created, it has a unique value for the attribute `ID`.

If ever you need to confirm whether or not an object is an instance of a particular class, use the `isinstance` function:

```
isinstance(hippo, Animal)
```

The `isinstance` function accepts two arguments and returns `True` if the first argument (typically an object) is indeed an instance of the second argument (typically a class).

The `pass` keyword doesn't tell Python to do anything (or, rather, it tells Python to do nothing!). It often serves as a placeholder for code in conditionals, loops, functions, or classes in Python:

```
class Reptiles(Animal):
    pass
```

Python will treat the above example as a regular class that doesn't do anything (without the `pass` keyword, Python may throw an error for not having anything in the body of the class).

Generators

A **generator** is a special type of function in Python that returns values in small parts rather than as a whole. They are written like regular functions with the exception of containing one or more `yield` statements in place of a `return` statement:

```
 def print_this():
    n = 1
```

```
    yield n

    n += 1
    yield n

    n += 1
    yield n
```

While a `return` statement returns a value and terminates a function, a `yield` statement returns a value and then pauses a function and saves the function's state for later use. In the above example, every time a `yield` statement is reached, it will return a value and pause the function until the function is called on again, at which point the function will pick up where it left off and continue running until it meets the next `yield` statement.

Generators are run using the `next()` (or `.__next__`) method. The first time `next()` is called on a generator, the function is run until it reaches the first `yield` statement. The generator will pause and not continue running until it is called by another `next()` method, at which point it will pick up where it left off and repeat the same thing.

```
a = print_this()

print(next(a))          # this will print, 1

print(next(a))          # this will print, 2

print(a.__next__())     # this will print, 3
```

If the generator is ever called more times than the yield statements it contains, it will raise a `StopIteration` error. Once a generator has been used to the end, it will need to be redefined for it to be reused (e.g. in the above case, `a` would have to be redefined as `a = print_this` once again).

Generators can be implemented in loops:

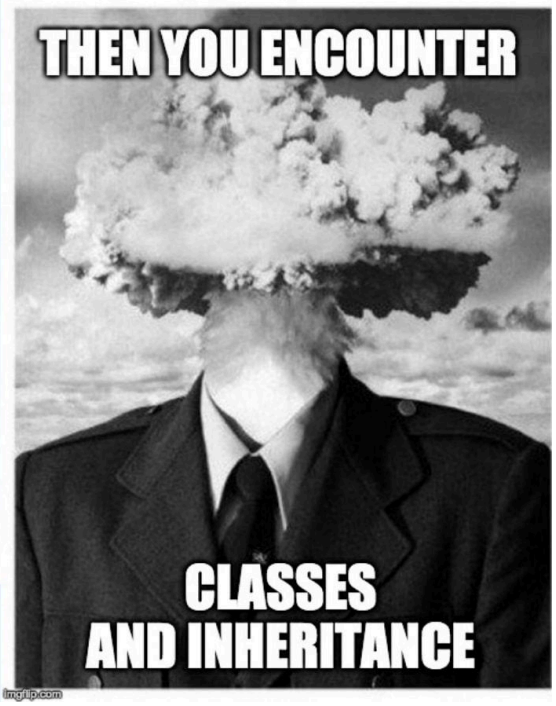
```
def countdown(num):
    print("Initiating countdown sequence.")
    while num > 0:
        yield num
        num -= 1
    print("Blastoff!")
```

The following is an example of the above generator being called:

```
blastoff = countdown(10)

blastoff            # returns something of the sort, <generator object
                      countdown at 0x10213aee8>

print(next(blastoff))      # prints, "Initiating countdown sequence."
                               10
print(next(blastoff))      # prints, 9
print(next(blastoff))      # prints, 8
```

`for` loops can be used to run all of the `yield` statements in a generator at once. `for` loops typically won't generate any `StopIteration` errors:

```
for iteration in countdown(10):

    print(iteration)
```



WEEK 6

Algorithmic Complexity

In programming, there can be multiple algorithms which can be used to accomplish the same task, albeit with varying levels of efficiency. An algorithm's efficiency is usually evaluated by its **order of growth**, or, the relationship between the size of the input it is given and the time it takes to complete the task. Several common types of orders of growth, including constant, linear, quadratic, logarithmic, and exponential orders of growth. Typically, the time a program takes to complete a task increases as the size of the given input increases.

Big O notation is a way to express the runtime of an algorithm as an order of growth. Typically, the worst-case scenario runtime of an algorithm is evaluated when using big O notation. When evaluating an algorithm's order of growth this way, the factors that have the greatest impact on the algorithm's runtime are often the factors that determine what order of growth the algorithm is categorized as. Smaller factors with lesser impact on an algorithm's runtime (especially in relation to the larger factors) are often neglected.

To determine the Big O notation of an algorithm, construct an equation that represents the number of steps of an algorithm in relation to the size of the input (which is represented using *n*). What counts as a step in a program is somewhat variable, but often includes the following:

- Mathematical operations
- Comparisons
- Assignments
- Accessing of objects in memory

Then, simplify the equation based on the factors which have the most impact on the runtime of the algorithm. Additive and multiplicative constants (such as *5* or *5n*) are usually dropped, and the whole equation is simplified to a single term based on the dominant factors of the equation:

$O(n^2)$: $n^2 + 2n + 2$

$O(n^2)$: $n^2 + 100000n + 3^{1000}$

$O(n)$: $\log(n) + n + 4$

$O(n \log n)$: $0.0001*n*\log(n) + 300n$

$O(3^n)$: $2n^{30} + 3^n$

The above examples show the big O notation of various equations. The term representing the Big O notation is preceded by a capital *O* and surrounded by parentheses. The last example especially illustrates how much big O notation is influenced by the dominant term(s) in an algorithm (i.e. although $2n^{30}$ is a very large number, 3^n has a greater impact on the algorithm's runtime as n increases).

- In Big O notation, when two sequential terms are added to each other in an equation, the lower of the two terms is dropped and the higher kept (this is known as the *law of addition*). The *law of multiplication* (primarily used when dealing with nested `for` loops) states that when there is a `for` loop nested in another `for` loop, the number of steps in each of the `for` loops are multiplied by each other to simplify both terms into one term.

- Note: when counting "steps" in a program, a `while` loop is always counted as at least one step since it must be evaluated at least once to determine whether to run or not (even if it doesn't actually satisfy the conditions to run). However, a `for` loop may not count as a step if there are no valid values for its counter variable to represent (as in `for x in []: ...`).

The following are several common orders of growth (also known as classes of complexity) in order of complexity (from lowest to highest):

$O(1)$ - constant runtime

$O(\log n)$ - logarithmic runtime

$O(n)$ - linear runtime

$O(n \log n)$ - log-linear runtime

$O(n^2)$ - quadratic runtime

$O(n^c)$ - polynomial runtime (where c is a constant)

$O(c^n)$ - exponential runtime (where c is a constant)

Simple Algorithms

Some relatively simple algorithms include algorithms of the search and sort classes of algorithms. Search algorithms find a specific element in a larger collection of data, while sort

algorithms organize collections of data. Search algorithms that are used on collections of sorted data are almost always faster than search algorithms that are used on unsorted collections of data.

The algorithm shown below is an example of a basic linear search algorithm that works on both sorted and unsorted collections of data:

```
def linear_search(element, some_list):
    for item in some_list:
        if item == element:
            return True
    return False
```

The above example systematically checks each element of `some_list` until a match with the parameter `element` is found. The algorithm's worst-case runtime would occur if there were no matches of `element` in `some_list` (*O: n*).

The algorithm shown below is a basic linear search algorithm that works on sorted collections of data:

```
def linear_search_2(element, some_list):
    for item in some_list:
        if item == element:
            return True
        elif item > element:
            return False
    return False
```

The above example systematically checks each element in `some_list` until a match with the parameter `element` is found or an element in `some_list` is found that is greater than the parameter `element` (at which point continuing the search would be pointless because all the other elements in the sorted collection of data would also be greater than the parameter `element`).

The algorithm shown below is an example of a bisection search algorithm that works on sorted collections of data:

```
def bisection_search(element, some_list):
    high = len(some_list)
    low = 0
    while True:
        middle = (high + low) // 2
        if some_list[middle] == element:
```

```
            return True
        elif high == low or high == low + 1 or high == low - 1:
            break
        elif some_list[middle] > element:
            high = middle
        elif some_list[middle] < element:
            low = middle
    return False
```

The above example checks to see if the element at the midpoint of `some_list` is the target element. If the element at the midpoint of `some_list` is larger than the target element, the algorithm repeats the same process for the lower half of the list (since in a sorted list, the other half of the list will always be larger than the target element). If the opposite is true, the algorithm repeats the same process for the upper half of the list (since in a sorted list, the other half of the list will always be smaller than the target element). The algorithm repeats this process until the target element is found or the section of the list it is searching is of the length `1` (at which point the target element is not found and there is nothing more to search). Since with every iteration of the while loop the above algorithm divides the input it is searching in half, the worst-case runtime for the above algorithm would be the logarithm of the size of the input it is given (*O: log n*).

Bubble sort is the name of a simple sorting algorithm that sorts a collection of data. The algorithm works by iterating through the data comparing two adjacent elements at a time, and leaving them in place if they are sorted, or swapping their positions if they aren't. This effectively "bubbles" the largest element in the data to the end of the data after one iteration, and the following iterations will continue to "bubble" the next largest elements in the data to the end of the data as well. This process is repeated until there are no more elements to sort in the data, and the data is then… sorted!

An example of a bubble sort algorithm is shown below:

```
def bubble_sort(some_list):
    is_sorted = False
    while not is_sorted:
        is_sorted = True
        for index in range(1, len(some_list)):
            if some_list[index] < some_list[index - 1]:
                 is_sorted = False
                 temp = some_list[index]
                 some_list[index] = some_list[index - 1]
                 some_list[index - 1] = temp
```

In the worst-case scenario, all of the elements in `some_list` would be in reverse order, and the algorithm would have to iterate through `some_list` n^2 times to put all of the elements in their correct place (*O:* n^2).

Selection sort is the name of another simple sorting algorithm that sorts a collection of data. The algorithm works by iterating through the data to find the smallest element and then swapping that element with the element at the beginning of the data. The algorithm then iterates through the data once again and finds the next-to-smallest element in the data and then swaps that element with the element in the place next to the beginning of the list. The algorithm repeats this process until the entire collection of data has been sorted.

The following is an example of a selection sort algorithm:

```
def selection_sort(some_list):
    sorted_index = 0
    while sorted_index != len(some_list):
        for index in range(sorted_index, len(some_list)):
            if some_list[index] < some_list[sorted_index]:
                some_list[sorted_index], some_list[index] =
some_list[index], some_list[sorted_index]
        sorted_index += 1
```

In the worst-case scenario, all of the elements in `some_list` would be in reverse order, and the algorithm would have to iterate through `some_list` n^2 times to put all of the elements in their correct place (*O:* n^2).

Merge sort is the name of yet another simple sorting algorithm that sorts a collection of data. The algorithm works by splitting an unsorted collection of data into halves and further dividing those halves into halves and dividing those halves into halves, etc. until each element in the collection of data is a separate half. Then, the algorithm merges all of those halves into pairs (or rather, sorted collections) and merges those pairs into pairs, etc. until the entire collection of data is sorted.

Merge sort merges collections of data by comparing the first element in one half of a sorted collection of data to the first element of an adjacent half of a sorted collection data and placing the smaller of the elements in a new, merged, sorted collection of data. Then the algorithm compares the next element in one half of a sorted collection of data to the element of the adjacent half of a sorted collection data and placing the smaller of the elements in the new, merged, sorted collection of data. Merge sort repeats this process until all the elements in both halves of the collections of data are stored and sorted in the new, merged collection of data.

WEEK 7

Plotting Graphs

There are a few modules included with Python that are able to construct graphs and plot points of data on them. One of these modules is named `pylab`.

To use `pylab`, simply import it using the `import` statement:

```
import pylab
```

To construct and plot points of data along a graph using `pylab`, use the `.plot()` function and provide the associated x and y values:

```
x_values = []
y_values = []

for i in range(30):
    x_values.append(i)
    y_values.append(i**2)

pylab.plot(x_values, y_values)
```

The above example plots a simple square function.

If you continue to construct additional graphs, their data will be plotted on the same window as your first graph. To create separate windows for separate graphs, use the `.figure()` function and provide the name you would like the graph to be referenced by, followed by a `.plot()` function of the graph:

```
y_values_2 = []

for i in range(30):
    y_values_2.append(i**3)

pylab.figure("another graph")
pylab.plot(x_values, y_values_2)
```

The above example constructs a separate graph (of a simple cubed function) that can be referenced again using the name `another graph`.

You can add titles and x-axis and y-axis labels to your graphs using the `.xlabel()` and `.ylabel()` and `.title()` functions:

```
y_values_3 = []

for i in range(30):
    y_values_3.append(i+5)

pylab.figure("yet another graph")
pylab.plot(x_values, y_values_3)
pylab.xlabel("these are the x values")
pylab.ylabel("these are the y values")
pylab.title("A Simple Linear Graph")
```

The above example constructs a graph (a simple linear function) and gives a title and some labels to a graph.

To manipulate graphs that have already been constructed and named, use the `.figure()` function again. All functions or methods in `pylab` that relate to graphs apply to the first graph created, or if the `.figure()` function has been used, to the graph specified by the most recent `.figure()` function. To clear a graph of its points and all other data (i.e. to make a new slate), use the `.clf()` function:

```
pylab.figure("another graph")
pylab.clf()
```

The above example clears the graph named `another graph`. Functions from `pylab` that are called apply to the graph referenced by the last `.figure()` statement.

You can add labels to the points plotted on a graph (using the label parameter of the `.plot()` function) and instruct `pylab` to display a legend showing those labels (using the `.legend()` function). You can also limit the range of the axes of the graph using the `.xlim()` and `.ylim()` functions:

```
pylab.figure("yet another other graph")
pylab.ylim(0, 1000)
pylab.plot(x_values, y_values, label="square function")
pylab.plot(x_values, y_values_2, label="cubed function")
pylab.legend(loc="upper left")
pylab.title("A Simple Linear Graph")
```

The above example limits the y-axis of a graph to `1000`, plots a square function and a cubic function on the graph, assigns separate labels to each of them, and instructs `pylab` to display a legend in the upper left corner of the window.

There are several ways to customize the way a graph is displayed. You can change the color and method of displaying the data in a graph by adding a string as the third argument to the function `.plot()`. The first character of the argument specifies what color the data should be. The next characters specify how the data should be displayed:

```
pylab.figure("a colorful graph")
pylab.plot(x_values, y_values, "bo", label="square function",
linewidth=2.0)
pylab.plot(x_values, y_values_2, "g^", label="cubed function",
linewidth=3.0)
pylab.legend(loc="upper left")
```

The above example constructs a graph of a square function displayed by blue circles (`b` for blue and `o` for circles) and a cubed function displayed by green triangles (`g` for green and `^` for triangles). Additionally, the `.plot()` function can take another argument called `linewidth` that specifies how thick the line (or shapes that make up the line) should be displayed (in pixels). See the `pylab` documentation for more coloring and display options.

Finally, you can specify how you want separate graphs to be plotted (within the same window) by using the `.subplot()` function. The `.subplot()` function accepts an integer argument of which the first digit determines how many rows of graphs should be displayed, the second determines how many columns of graphs should be displayed, and the last specifies the order of the graph of the next `.plot()` function:

```
pylab.figure("two graphs in one")
pylab.subplot(211)
pylab.ylim(1000)
pylab.plot(x_values, y_values)
pylab.subplot(212)
pylab.ylim(1000)
pylab.plot(x_values, y_values2)
pylab.yscale("log")
```

The above example creates a window with two graphs (one of a square function, the other of a cubed function, both with a y-axis limit of `1000`) and constructs each graph on a separate row in a single column (`2` for the number of rows, `1` for the number of columns, and `1` and `2` for each of the graphs, respectively). The additional function call (`.yscale()`) specifies to display the y-axis as a logarithmic scale (`"log"`) instead of a linear scale (which can be useful in some instances).

Some other useful links:

[An Informal Introduction to Python – Python 3.8.5 documentation]
[How To Code in Python 3]
[Real Python: Python Tutorials]

...

Enjoy 6.00.1x!

ApplePieGiraffe

🍏🥧🦒