Abstract

Lecture notes for an introductory programming course in Python (version 3.x). There are many example problems suitable for "flipped" classes. This follows the order of Allen Downey’s Think Python text. Some sections are skipped, but the basics are included through inheritance and polymorphism. No prior programming experience is expected.

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0 Course Intro

0.1 The Course’s Textbook

The text for this class is Dr. Allen Downey’s “Think Python: How to Think like a Computer Scientist”. The second edition of the book is available at http://greenteapress.com/wp/think-python-2e/\(^1\).

These notes do not cover all parts of the textbook; I skip parts that I don’t get to address during the semester, though I do cover some of the topics in more depth (or just provide additional examples and in-class exercises).

0.2 Acknowledgements

Incredible thanks to Allen Downey, my first CS professor back in the Fall of 1999. He made an impression in only one semester; his enthusiasm, attitude, and clarity are all qualities I have tried to emulate in my own teaching career. In addition, his introductory programming text (which these notes use) is excellent.

Thanks to Christin Wixson for helping me prepare these notes for adoption as an Open Educational Resource (OER). Her help has been invaluable in preparing this for the public, including navigating the ramifications of licenses. The entire Plymouth State repository of OERs is available at https://digitalcommons.plymouth.edu/oer/.

Most of all, thanks to the many students that took this course from me at Wittenberg University, Colby College, and Plymouth State. You have each taught me how to be a better teacher, and I wish I had all the tools I have now when I met you.

0.3 In Progress

- Translate the examples/questions from Python 2 to Python 3. The biggest recurring change here is that in Python 3, `print` is a function instead of just a special command.
- Adapt to the other changes in the second edition of Think Python.
- Add more Bonus Challenge problems throughout the notes so that there’s (nearly) always something for students to be working on.

\(^1\)PDF (free and legal) available at http://greenteapress.com/thinkpython2/thinkpython2.pdf
1 The Way of the Program

Welcome to Introduction to Programming! In this class, you are going to learn to write programs! Exciting!

More goals:

• Learn an approach to problem solving, including:
  – stating problems clearly
  – creatively devising solutions
  – clearly expressing solutions

• Learn to think Algorithmically. "What’s a good way to complete this task?"

• Learn to write computer programs. Sounds tricky, but we’re going to do it!

1.1 Python

We are going to learn Python, a high-level programming language (like C++ or Java).

Def: Low-Level Language A low-level language is something written so the hardware can read it. Examples: machine code or assembly language.
Q: Why aren’t we learning a low-level language?

A: 

Q: How does a computer run a program?

A: 

This slows down processing time a bit, but *greatly* speeds up the programming time.

Two flavors of high-level languages:

- Interpreted: Source Code $\xrightarrow{\text{Interpreter}}$ Output
- Compiled: Source Code $\xrightarrow{\text{Compiler}}$ Executable Program $\xrightarrow{\text{Executor}}$ Output

TODO: draw picture

( Say something about each! )
Q: Which of the two is Python?

A:

Q: Why use a compiled language?

A:

Two modes for running Python code:
- Interactive Mode: "Chat" with Interpreter.

```python
>>> 2+2
4
>>> 
```
- Script Mode: Store Programs in a .py file.

Q: When might you want to use each mode?

A:
1.2 What is a Program?

Q: What is a program?

A:

Common types of instructions:

• Input
• Output
• Math
• Conditional Execution
• Repetition

Every program you’ve ever seen is built from these pieces!

I will teach you to do this!

Since instructions need to be unambiguous, code must be precise and clean. Errors that humans could resolve, computers have a hard time with.

1.3 What is Debugging?

Debugging!

“Bugs”: Rear Admiral Grace Hopper.

Def: Debugging: tracking down errors and fixing them.

Aside from Termintator-like scenarios, this is the biggest thing people complain about with computers.
Three types of errors:

- **Syntax Error.** Syntax are rules about structure. Example: ```python >>> 2 + ) 2```. Try it out!
  Like English grammatical errors. Python checks first; one syntax error prevents WHOLE program from running. You’ll make lots of these in the beginning, but will get better.

- **Runtime Errors.** “Exceptions.” Happen while program is running.

- **Semantic Errors.** Program runs and doesn’t notice a problem, but it doesn’t do what you wanted. Example: Want the computer to print the word `Monkey!`, but instead you accidentally type: ```python print('Donkey!')```. (Try this out!) It doesn’t do what you want, but it doesn’t realize it’s done anything wrong.

**Q:** How do you know if you have errors in your code?

**A:**

Debugging is hard, but is a useful skill! Even outside of programming! Like forensics: need to find culprit. Error messages give you clues.

Debugging is an experimental science:

- Have an idea about what went wrong.
- Try to fix it.

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1.3 What is Debugging? 1 THE WAY OF THE PROGRAM

- Run it again to see whether that worked.
- If not, maybe you need a new idea!

The book discusses debugging issues at the end of each chapter. Look there if you’re having trouble!

Good idea: Purposefully make some mistakes! Learn what happens and become unafraid of errors! Let’s do some of that now.

Q: Let’s try causing some different types of exceptions. Give me a line of code that causes a TypeError.

A:

```python
3 + "3"
```

Traceback (most recent call last):
File "<stdin>", line 1, in <module>
TypeError: unsupported operand type(s) for +: 'int' and 'str'

Q: Let’s talk quickly about the info Python gave us back from this error. Why does it say ”line 1”?

A: The error happened in the first line of the code. If we have a longer program in a script, this could be in a line other than 1.
Q: What is Python telling us in the last line of the error message?

A: 

- TypeError: means it was trying to do something, but it couldn’t because the types of the values weren’t correct.
- Message (last line): It’s saying that it doesn’t know how to add an int to a str.

TODO: divide this up into things you expect they might know about versus things they certainly don’t know about yet!
1.3 What is Debugging?

Q:

Try to generate the following errors in interactive mode. For each error type, see if you can come up with a line (or lines) of code that causes that type of error. (We’ve already seen TypeError, so I’m not including that.)

• NameError
• ZeroDivisionError
• ValueError
• AttributeError

Bonus: how do you cause a KeyboardInterrupt?

A:
1.3 What is Debugging?

These are errors you might see later on in the course. Does anyone know how you might cause any of these?

Q:

- ModuleNotFoundError
- IndexError
- KeyError
- FileNotFoundError

A:

- ModuleNotFoundError:
  >>> import bananaCheese

- IndexError:
  >>> monkeys = ['tamarin']
  >>> monkeys[1]

- KeyError:
  >>> belugas = dict()
  >>> belugas['cheese']

- FileNotFoundError:
  >>> open('AshKetchum.txt')

There are even more kinds of errors here: https://www.tutorialspoint.com/python/standard_exceptions.htm.
Q: You can cause an exception that you create to occur. How does that work?

Do something like this:

```python
>>> raise Exception("I don’t know what I’m doing!"")
Traceback (most recent call last):
File "<stdin>", line 1, in <module>
Exception: I don’t know what I’m doing!
>>>```

A: Natural and Formal Languages

Def: Natural Languages are those people speak or use to converse with other people.

3Source: https://twitter.com/SashaLaundy/status/936661004137635840
These are designed by people, but come about naturally.

**Def:** *Formal Languages* Formal Languages are designed by people for a specific purpose, like programming languages.

**Q:** What are other types of formal languages?

**A:**

Formal languages are very strict about syntax.

**Q:** What are examples of syntactically incorrect mathematical and chemical statements, but which use correct words and characters?

**A:**

**Def:** *Tokens* Tokens are basic elements of a language. For example: words, numbers, chemical elements.

**Def:** *Structure* Structure is rules for arrangement of the language’s Tokens.

Pulling apart statements to analyze structure and tokens is called *parsing*. We do this unconsciously in English!

Three properties of languages:
1.4 Natural and Formal Languages  

- Ambiguousness
- Literalness
- Redundant

<table>
<thead>
<tr>
<th>Q:</th>
<th>Which of these is:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• more ambiguous?</td>
</tr>
<tr>
<td></td>
<td>• more literal?</td>
</tr>
<tr>
<td></td>
<td>• more redundant?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>A:</th>
</tr>
</thead>
</table>

Informal → Formal: Poetry → Prose → Programs

<table>
<thead>
<tr>
<th>Q:</th>
<th>Reading Code is Hard! Why?</th>
</tr>
</thead>
<tbody>
<tr>
<td>A:</td>
<td></td>
</tr>
</tbody>
</table>

You will learn to deal with all of these things! You will both READ and WRITE code well! Debugging: you will get frustrated.
• People often respond to computers as though they were people!
• Errors are ”Rude”! They will not always be clear!
• Computer is good at speed, not good at empathy!

Sleep on it if you have to! Take a walk. Change the music you’re listening to. Switching your environment can often help you change the way you’re thinking.

2 Variables, Expressions and Statements

2.1 Values and Types

Def: Values Values are basic data used by a program.

```python
>>> 1 + 2
3
```

That uses the values 1 and 2. In lab, used value: ‘Hello, World!’
There are different value types:
• 1,2: integers
• ’Hello, World!’: string. “string” of letters. Strings are always in quotes!

Sometimes you need double-quotes in strings

```python
>>> 'That’s all folks!'
Syntax Error!
>>> "That’s all folks!"
```

Python can identify types for you!
2.1 Values and Types

```python
>>> type('Hello, World!')
<class 'str'>
>>> type(42)
<class 'int'>

Q: What’s going to happen here?

>>> type(3.25)

A: `float` means Floating-Point. That means it’s a number with a fractional part.

Q: What’s going to happen here?

>>> type('3.25')

A:
Q: Why?

A: 

```python
>>> print(42)
42
>>> print('42')
42
>>> print(1,000,000)
1 0 0
```

Q: What happened there?

A: 

Q: What kind of error did I get?

A: 

```python
>>> type(1,000,000)
Traceback ...
```
2.2 Variables

Q: What happened there?

A: 

Q: What kind of error did I get?

A: 

2.2 Variables

Def: A variable is “named storage” for a value.

Create variables with assignment statements:

```python
>>> message = 'I love variables!'
>>> number = 42
>>> pi = 3.14...
```

Add and describe: state diagram!
2.3 Variable Names and Keywords

Variable Names must be:

- Legal. Illegal things include:

```python
>>> 3age = 84
SyntaxError: invalid syntax.
```
Variable names must begin with a letter!

```python
>>> phone@home = 9375555555
```
@ is an illegal character!

```python
>>> important variable = 42
```
No spaces! Use snake_case!

```python
>>> important_variable = 42
```

```python
>>> import = 'cupcakes'
```
import is a keyword: full list in the book.

- Meaningful!
  Variable names should describe the purpose or role of the variables.

Which of the following variable names is best?

**Q:**
- number = 5
- number_of_tigers = 5
- number_of_tigers_at_zoo = 5

**A:**

A common convention is to drop the "ber_of" part,
so you could name your variable `num_tigers_at_zoo` and that’s completely fine.

### 2.4 Statements

### 2.5 Operators and Operands

We can use operators with values and variables. Math operators include: `+`, `-`, `*`, `/`, `**`.

```plaintext
>>> 33-28
5
>>> 3**2
9
>>> number-3
39
>>> 1/2
0
>>> 1.0/2
.5
>>> 1.0 // 2
0.0
>>> .1 + .2
.30000000000000004
```

**Q:** What’s going on with these last two?

**A:** The `//` operator divides and removes any remainders. The last one is the closest number Python can recognize near .3.
2.6 Expressions

These are all expressions: combinations of values, variables and operators.

\[(2\times7)\times(1+2)\]

In interactive mode, after typing in an expression, in-

\[\text{Prove you are human:}
\]

\[0.1 + 0.2 = \, ?\]

\[0.3000000000000004\]

\[\text{EARLIER...}
\]

\[\text{WELCOME TO THE SECRET ROBOT INTERNET}\]
2.7 Order of Operations

Without trying them out, what is the result of each of these? (Write them on the board.)

- $2^2 \times 2$
- $(2^2) \times 2$
- $2^{2 \times 2}$
- $5/2 + 1$
- $1 \times 1 + 1^{1}$
- $1 \times (1+1)^{1}$

A:

I always use parameters to make things clear!
2.8 String Operators

Some of these work on strings too!

```python
>>> last_name = 'Stickney'
>>> print('2 ' + last_name)
2 Stickney
>>> print(3*'Monkey')
MonkeyMonkeyMonkey
```

String “adding” is known as *concatenation.*

Sometimes you want to print strings and non-strings in the same line. `print` can do this!

```python
(In script)
number_of_squirrels = 5
print('''I have'', number_of_squirrels,
''''squirrels, isn’t that nice?’’)
```

Q: What happens when you run this?

A:

Q: What if I change the 5 to a 75 and rerun it?

A:
### Single vs Double quotes

Notice that we can use both single quotes or double quotes for strings:

```python
>>> 'Hi, everyone!'
'Hi, everyone!'
>>> "Hi, everyone!"
'Hi, everyone!'
```

**Q:** Why is that?

**A:** Sometimes you want to put quote marks in a string.

**Q:** How can I create the string: *It’s a complete mystery...!*?

**A:**

**Q:** What happens if we try to create that using single quotes?

**A:** It thinks the string ends after the It.
2.9 Comments

Code can be tough to read!

- Expressions are complex
- Whole sections can be complex

Solution: Comments!
Def: Comment A comment is a note to yourself and other programmers, but not to Python. 
In script:

```python
#compute the circumference of the circle
circumference = 2 * radius * pi
```

Or it can be on the same line:

```python
area = pi * radius**2 #area of a circle
```

# symbol tells the interpreter to ignore the rest of the line. For humans, but not machines!

<table>
<thead>
<tr>
<th>What is wrong with these?</th>
</tr>
</thead>
<tbody>
<tr>
<td>•</td>
</tr>
</tbody>
</table>

Q:

•

monkey = 16 #assign monkey to 16

monkey = 16 #monkey is driving time to Indianapolis in hours

A:
Q: What would be better?

A: TRADEOFF! Variable names vs. comments

- longer variable names: easier to understand the role
- shorter names: expressions are easier to visually parse

In general, I err towards longer names.

3 Functions

Def: Function In programming, a function is kind of like a subprogram:

- Like a program, it also a sequence of instructions
- ...But, has a name like a variable

3.1 Function Calls

You can use or call functions inside a program once they’re defined.

```
>>> type(42)
<type 'int'>
```

5Excellent list of useless comments here: http://www.neobytesolutions.com/the-least-useful-comments-ever/
Let’s dissect this:

```python
>>> type (42)
<type 'int'>
```

Say: function “takes” argument and “returns” the result.

### 3.2 Type Conversion Functions

Some other functions are already defined in Python. For example: Type Conversions! Sometimes you want to convert a variable from one type to another.

```
>>> int(3.0)
3
>>> int(2.7182817284)
2
>>> int(42.7)
42
```

**Q:** How would you describe what the `int` conversion function does to floating-point values?

**A:**

---

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3.2 Type Conversion Functions

Q: Test-Focus: What could we do to test this in a new way?

A:

```python
>>> int(-3.45)
-3
```

Q: What do you think it does now?

A:
For each of these, guess at what you think the value is that’s returned, then try it out:

```
>>> float(3)
```

```
>>> float(42.7)
```

```
>>> str(32)
```

```
>>> str(32.0)
```
3.2 Type Conversion Functions

Do the same for these:

>>> int("34")

>>> float("34.0")

>>> int("34.0")

>>> float("34")

Q: What will happen with the call int('monkey')?

A:
3.3 Math Functions

Also, you might want to use some ‘popular’ math functions: logarithms, trig, square root. They exist in `math` module.

**Def:** module A module is a collection of pre-defined variables and functions.

Loading the module is easy!

```python
>>> import math
```

Just like a variable, this is cleared when we restart interactive mode by running a script. If you use `math` in your script, put `import math` at the top.

```python
>>> math.pi
3.1415926535897931
```

This is the closest number to pi that Python can represent, stored in the variable `math.pi`. Many useful math functions! Say we want to find the sine of 1.5 (radians).

```python
>>> math.sin(1.5)
.997...
```

“dot notation”

```
math • sin(1.5)
```

We can use variables as the arguments!

```python
>>> radians = 1.5
>>> math.sin(radians)
.997...
```
3.4 Composition

math.sin expects the argument to be in radians. What if I have the number of degrees instead?

Help me fill in the following code!

(In script)
import math
degrees = 200
radians = ...
print(math.sin(radians))

This should print: -.3420

How hard is it to change this script to try it with a different number of degrees?

You can also use expressions inside arguments!
Q: In interactive mode, how do I compute this: $\sqrt{1 + 50}$?

A:

You can also use function calls inside other expressions!

Q: What about $\sqrt{\frac{3}{6}}$?

A:

If I wasn’t sure that my solution was correct, I could check in two lines:

```python
>>> x = math.sqrt(3)
>>> x/6
...```

Q: What about: $\sin\left(\frac{1.5^2}{2}\right) - 1$?

A:
3.5 Adding new Functions

```python
>>> x = 1.5**2
>>> y = x / 2
>>> z = math.sin(y)
>>> z - 1
-.997...
```

Q: What about: \( \cos(\sqrt{1.21}) \)?

A:

Composition! You can have multiple levels of composition!

Q: We saw the issue with trying to convert "34.0" into an int. However, int(34.0) isn't a problem. How could we use this to get around the first problem?

A:

3.5 Adding new Functions

Q: What if no function does what you want?

A:
3.5 Adding new Functions

(In script!)
def print_favorite_word():
    print('monkey')

Let’s look more closely!

Break down:

```python
def print_favorite_word():
    print('monkey')
```

Although you can define functions in interactive mode, it’s better to use script mode!

```python
>>> print_favorite_word()
monkey
```

A function body can have multiple lines!

(In script!)
def print_favorite_words():
    print('monkey')
    print('bonus')
    print('awesome')

Run the script, then:

```python
>>> print_favorite_words()
monkey
bonus
awesome
```
What happens if you define `print_favorite_word` twice?

(Add to bottom of script)
def print_favorite_word():
    print('awesome')

Q: Which word will be printed when I call `print_favorite_word`?

A: 〈 Delete the second definition from the script. 〉

Q: How could you write the function, `print_kyles_favorite_word_twice` that printed out my favorite word twice?

A:

```python
>>> print_kyles_favorite_word_twice()
monkey
monkey
```
Q: When I wake up tomorrow, what if I change what my favorite word is? I change `print_favorite_word` but not the others! Can I change `print_kyles_favorite_word_twice` so that this isn’t a problem?

A:

```python
>>> print_kyles_favorite_word_twice()
monkey
monkey
```

Another form of function composition!

### 3.6 Definitions and Uses

(I skip this section in class.)

### 3.7 Flow of Execution

Let’s look at how this works! “Flow or Thread of Execution!”

Demonstrate flow, first on `print_favorite_word`, then from `print_kyles_favorite_words`.

Function calls are like detours. When you are reading a program, be sure to follow the flow. At a function call, read through the call before continuing.
3.8 Parameters and Arguments

So far, we haven’t shown how to use arguments!

```
math.sqrt(argument)
```

⟨ Load the chapter 3 code! ⟩

For example, maybe I want a function that greets a friend:

```
>>> greet('Bob')
Hi, Bob!

>>> greet('LuAnn')
Hi, LuAnn!
```

Solution: Parameters! (We’ll work on defining `greet` in a little bit; hold on.)

**Def:** *Parameters* *Parameters* are variables that are assigned to the arguments of a function.

```
(On board)
def print_twice(message):
    print(message)
    print(message)
```

**Q:** What will happen when we do this?

```
>>> print_twice('spam')
```

**A:**
Try it out! Write the function in script mode and then call it in interactive mode!

Q: What does the following function call do?
   >>> print_twice('Spam' * 4)

A:

Q: Follow Up!
   What is the value of message inside the function?

A:

Q: What about the following?
   my_name = 'Kyle'
   greet(my_name)

A:
3.9 Variable Locality

Note: parameters are local! They do not persist outside of the function!

```python
>>> message
Error!
```

A common error with parameters is to redefine the variable!

```python
def print_twice(message):
    message = 'spam'
    print(message)
    print(message)

Now print_twice only works with 'spam'!
```

```python
>>> print_twice('spam')
spam
>>> print_twice('spamalot')
spam
```

This is common! Don’t redefine your parameters!

```python
>>> greet('Bananaman')
Hi, Bananaman!
```

```python
>>> brag_about('Elman Bashar')
Wow, Elman Bashar is definitely the coolest person I know. They are just so awesome!
```

```python
```
3.9 Variable Locality

How can we write the `greet` function?

**Q:**

Header: `def greet(name):`

Bonus Challenge: `brag_about`

**A:**

Problem here?

**Q:**

**A:**

How can we fix this?

Hint: use string concatenation.

**Q:**

**A:**

What if `name` is not a string?

```python
>>> greet(5)
Error!
```
Q: How can we fix this?
   Hint: use type conversion!

A:

Try out the following cases

```python
>>> name = 'Kyle'
>>> greet(name)
Hi, Kyle!
>>> greet('name')
Hi, name!
>>> greet(Name)
Error!
```

```python
>>> greetwhole_name('Kyle', 'Burke')
Hi, Kyle Burke!
>>> greetwhole_name('Ash', 'Ketchum')
Hi, Ash Ketchum!
>>> super_brag_about('Elman', 'Bashar')
Wow, Elman Bashar is definitely the coolest person I know. They are just so awesome! Elman can jump through hoops of fire and once bested a Siberian Horsetiger in a game of Chessboxing!
```
Q: How can I write the body of the `greet_whole_name` function?

Header: `def greetWholeName(first_name, last_name):

Bonus Challenge: `super brag about`.

A:

Or, could create a new variable inside the body.

```python
def greet_whole_name(first_name, last_name):
    whole_name = str(first_name) + " " + str(last_name)
    print('Hi, ' + whole_name + '!')
```

Q: Did I make a mistake by not putting `str(whole_name)` in that last line?

A:

Q: Which one do I like better?

A:
Q: Can we do even better?

A:

Q: Which function body does the last line of the last `greet_whole_name` look like?

A:

Q: Could we replace with a call to `greet`?

A:

Q: Why is this considered better?

A:

Actually a big part of Software Design. When I change code, try to change it in fewest places possible. Good code allows for this!
3.10 Stack Diagrams

Things can get confusing! Sometimes we need to keep track of variable locality. Use a stack diagram!

Do stack diagram for the last code example. __main__

>> first_name = 'MC'
>>> greet Whole_name(first_name, 'Frontalot')
Hi, MC Frontalot!
>>> print(first_name)
MC
>>> print(whole_name)
Error!

Q: Why did I get that error?

A:

Q: Why not with first_name?

A:

>> greet Whole_name('Mr.', first_name)
Hi, Mr. MC!

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3.10 Stack Diagrams

Your turn!

(script)
def concatenate_twice(message_one, message_two):
    full_message = message_one + message_two
    print_twice(full_message)

What do the stack diagrams look like for this call?

Q:

>>> spanish = 'Hasta la vista, '
>>> english = 'baby.'
>>> concatenate_twice(spanish, english)

Try it out and check with your neighbors!

Stack diagrams very helpful for figuring out what went wrong! Use them on projects!

(interactive mode)
>>> print_product(5, 3)
5 times 3 = 15
>>> print_product(9, -7)
9 times -7 = -63
>>> print_power(3, 3)
3 raised to 3 = 27
>>> print_power(-1, 7)
-1 raised to 7 = -1

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Q: Implement `print_product`! Bonus challenge: `print_power`.

A:

Let’s make use of Einstein’s famous Mass-Energy equivalence! \( E = mc^2 \)

(Interactive mode)

```python
>>> print_energy(50)
50 grams contains 4493775893684088200 available joules.

>>> print_energy(.001)
.001 grams contains 89875517873691.77 available joules.

>>> print_quadratic_roots(4, 0, -4)
4x^2 + 0x + -4 has roots 1.0 and -1.0.

>>> print_quadratic_roots(1, 3, 2)
1x^2 + 4x + 2 has roots -0.5857864376269049 and -3.414213562373095

>>> print_quadratic_roots(1, 2, 3)
Error!
```
3.11 Fruitful and Void Functions

There’s still something different about the math functions we used!

```python
>>> math.sqrt(16)
4.0
>>> math.sqrt(math.sqrt(16))
2.0
```

Q: What’s different?

A:

Def: Fruitful and Void Fruitful functions return a
value. Void functions do not (they actually return None).

I could write that last part as:

```python
>>> x = math.sqrt(16)
>>> math.sqrt(x)
2
```

I wanna do that too! So far: we can’t! Try:

```python
>>> greeting = greet('Hercule')
Hi, Hercule!
>>> print(greeting)
None
```

None is a special value: represents no actual, usable value (nothing was assigned). It even has it’s own type!

```
>>> type(None)
<type 'NoneType'>
```

**Def:** void The functions we’ve written are void, which means they have no return value.

We will write fruitful functions soon... in chapter 5.
3.12 Why Functions?

Q: Why do we want to write functions anyways?

A: 

4 Repetition and Turtles

In programming, there is lots of repetition!

For example, we might want a function that greets multiple times!
4.1 Turtles

In the next lab, you will steer a turtle! Turtles like to draw!

WARNING: do not name your script 'turtle.py'

Now I can create a Turtle and get it to do stuff!

Notice: some PascalCase coming up—used for class names. Classes are more complicated types than int or str.

```python
>>> import turtle
>>> raphael = turtle.Turtle()
>>> raphael.fd(100)
>>> raphael.rt(90)
>>> raphael.fd(100)
```
Q: What would it take to draw a square with side length 50 and end up facing the same way we started?

A:

4.2 Simple Repetition

Lots of repetition! Same thing four times! Let’s simplify with for!

```python
>>> for i in range(3):
    print('Monkey')
Monkey
Monkey
Monkey
```
Q: How can we use this to condense the square-drawing program?

A: 

Break down:

```
for i in range(4):
    fd(bob, 50)
    rt(bob)
```

This is known as a *for loop*.

Q: Why is this helpful?

A: 

Q: Change it, how?

A: 

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Q: How many places would we have to change it before? How many now?

A: Huge improvement!
We can put a loop inside a function!

How would you write `greet_n_times`? Header:

Q:

```python
def greet_n_times(name, n):
```

A:

Let’s write some functions for our turtles using loops!

4.3 Exercises

4.4 Encapsulation
Ugh, there’s flatcase. As much as I don’t like snake_case, I like flatcase even less. (My favorites are camelCase and PascalCase.)
Q: Implement it! Header: `def draw_square(turtle):` Bonus challenge: `draw_plus_sign`

A:

```python
>>> screen = raphael.getscreen
>>> screen.clearscreen()
>>> donatello = turtle.Turtle()
>>> donatello.penup()
>>> donatello.forward(100)
>>> donatello.pendown()
>>> draw_hexagon(donatello)
<donatello draws a hexagon with side length 70>
>>> metalhead = turtle.Turtle()
>>> metalhead.penup()
>>> metalhead.back(100)
>>> metalhead.pendown()
>>> draw_star(metalhead)
<metalhead draws a 5-pointed star>
```
Q: Implement `draw_hexagon(turtle)`! Bonus challenge: `draw_star`

A:

```python
>>> screen.clearscreen()
>>> raphael = turtle.Turtle()
>>> raphael.left(90)
>>> draw_box_stack(raphael, 4)
>>> michelangelo = turtle.Turtle()
>>> michelangelo.penup()
>>> michelangelo.forward(100)
>>> michelangelo.pendown()
>>> draw_box_grid(michelangelo, 5)
```

Next: let’s make these functions more useful!

We might do a lot of square drawing. Perhaps we are drawing lines for four-square! Before our function creation, our code might have looked like:

```python
for i in range(4):
    fd(raphael, 100)
    rt(raphael)
```

for i in range(4):
    fd(raphael, 100)
    rt(raphael)
.
.
.
for i in range(4):
    fd(raphael, 100)
    rt(raphael)

We simplified this by replacing the repetitive code with function calls! Now our code might look like:

draw_square(raphael)
.
.
.
draw_square(raphael)
.
.
.
draw_square(raphael)
    Known as Encapsulation.

**Def:** Encapsulation Encapsulation: repeated code block $\rightarrow$ put code in function, replace blocks with function call.
4.5 Generalization

Q: What else could we do with `draw_square` and `draw_plus_sign`?

A: Let’s make it so we can draw them of any size!

```python
>>> screen.clearscreen()
>>> leonardo = turtle.Turtle()
>>> leonardo.penup()
>>> leonardo.forward(100)
>>> leonardo.pendown()
>>> draw_square(leonardo, 25)
<leonardo draws a square with side length 25>
>>> donatello = turtle.Turtle()
>>> draw_plus_sign(donatello, 35)
<donatello draws a plus sign with width and height 35>
```

A:

This is Generalization!

**Def:** Generalization Generalization: function specific to one value → function applicable to different values by adding parameters

```python
>>> draw_square(leonardo)
```

Q: What happens when you try that?

A: Error! But mine works (just like before, it draws a square with sides of length 100).
Q: How can we get it to use 100 if we don’t specify it?

A: Use a default parameter. Change the header to look like this:

```python
def draw_square(turtle, side_length=100):
```

Q: Can we generalize `draw_hexagon` in the same way?

A: Absolutely!

Q: Do it! Bonus challenge: `draw_star`

A:
4.5 Generalization

Q: Which two functions are very similar?

A:

Q: Should we generalize these into one function?

A:

```python
>>> draw_polygon(leonardo, 9, 30)
>>> draw_polystar(donatello, 7, 30)
```

Q: Which parameter are we adding?

A:
Q: Implement it! Header:

```
def draw_polygon(turtle, num_sides, side_length):
    Hint: total angle degree is 360.
    Bonus Challenge: draw_polystar
```

A: 

Q: Is this a version of generalization?

A: Yes!

Q: What other functions can we generalize?

A: draw_box_stack and draw_grid
Q: Do `draw_box_stack`. Bonus challenge: `draw_grid`

A:

4.6 Interface Design

Let’s try drawing a circle! Let’s approximate (often the best we can do with computers) by drawing a polygon with lots of short sides.

```python
>>> for i in range(180):
    fd(bob, 4)
    rt(bob, 2)
```

Q: Is this something we might do a lot?

A:
Q: What should we do, then?

A:

>>> bobDrawCircle()

Do it! Header:

Q: Can we rewrite this by calling drawPolygon?

Hint: in the book

A:
Q: What should we do to improve `bobDrawCircle`?

A: First, let’s rewrite to use any turtle.

```python
>>> drawCircle(bob)
>>> sally = Turtle()
>>> drawCircle(sally)
```

Implement it! (Change the original one!) Header:

Q:

```python
def drawCircle(turtle):
```

A: Now the radius! More tricky, need to calculate the circumference!

```python
>>> drawCircle(bob, 50)
>>> drawCircle(sally, 125)
```
Implement it! (Change the original one!) Header:

Q:
```
def drawCircle(turtle, radius):
```

Hint: last line is: `drawPolygon(turtle, numberOfSides, sideLength)`
Double Hint: It’s in the book!

A:

Q:
Should we generalize to add `numberOfSides` as a parameter?

Q:
Is this appropriate?

A:
>>> drawCircleBad(bob, 75, 50)
>>> drawCircleBad(bob, 100, 12)

Q: Is this appropriate?

A:

turtle and radius describe what is to be drawn. numberOfSides describes how functions should always work. Arguments should tell them what to do, but not necessarily how to do it. Assume they know best how to do it already!

Def: Interface A function’s interface includes what a function does, arguments and a return value, if any.

4.7 Refactoring

4.8 Docstrings

(Order swapped with Development Plan.) Interfaces should be as uncluttered as possible. Use docstring to describe a function’s interface!

Def: docstring A docstring is a string used to describe a python function’s interface. It should be in triple quotes and belongs directly after the header.
def greet(name):
    '''Prints out a greeting to someone called name.'''
    print('Hi, ' + str(name) + '!

Notice, it’s still indented over!

Q: Try adding a docstring to drawSquare!

A:

docstrings:
• use triple quotes, so it can be a multi-line string!
• explains what, but not how.
• shouldn’t be too hard to write. If it is, indication of inappropriate function.
• do for all functions! I will now deduct points if they’re not there!

An Interface is a contract between the function and the user.
• User promises to provide appropriate arguments.
• Function promises what it will do/accomplish.
4.9 Development Plan

Now we have a good plan for writing programs:

- Write a small program with no functions.
- Get it working.
- Encapsulate it into a function.
- Generalize the function by adding parameters.
- Start writing the next part of your program outside of any function.
- Repeat the steps above to build a complete set of functions.
- Look for places to rework your functions to improve interfaces and remove code re-use.

When writing functions, use the following order:

- Write the header.
- Write the docstring.
- Add the body.

This way you know what you’re expecting your function to do logistically.

5 Conditionals and Recursion

5.0 The Modulus Operator

New Math:
**5.0 The Modulus Operator**

>>> 13 / 4
3 ("Quotient")

>>> 13 % 4
1 ("Remainder")

**Def:** \% is the modulus operator.

>>> 12 % 3
0

>>> 100 % 20
0

**Q:** When is \(x \% y\) zero?

**A:** When \(x\) is divisible by \(y\).
5.0 The Modulus Operator 5 CONDITIONALS AND RECURSION

```python
>>> print_minutes_hand(17)
17 minutes after noon, the big hand is pointing to 17 minutes.
>>> print_minutes_hand(213)
213 minutes after noon, the big hand is pointing to 33 minutes.
>>> print_both_hands(213)
213 minutes after noon, the big hand is pointing to 33 minutes, and the little hand is pointing to 3 hours.
>>> print_both_hands(1000)
1000 minutes after noon, the big hand is pointing to 40 minutes, and the little hand is pointing to 4 hours.
```

Q: Implement `print_minutes_hand` without using if! Header: `def print_minutes_hand(minutes):` Bonus challenge: `print_both_hands`.

A: 

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5.1 Boolean Expressions

New Data Type: Booleans! Used to represent “Truthiness”. Only two values: True and False

>>> True
True
>>> False
False
>>> type(True)
<type 'bool'>
>>> not False
True
>>> x = True
>>> x
True
>>> not x
False

We can have expressions that return a boolean value!
For example, test whether two things are equal!
5.2 Logical Operators

We also have operators that take booleans: and, or, not.

Note: HAVE to use double equals when testing for equality!

```python
>>> 5 == 5
True
>>> 5 == 6
False
>>> 5 < 6
True
>>> 5 > 6
False
>>> 5 >= 6
False
>>> not (5 == 6)
True
```

```python
>>> 5 = 6
Error!
```

```python
>>> x = 4
>>> y = 8
>>> not (x == y)
True
>>> x != y
True
```
>>> True or False
True
>>> False or False
False
>>> True and False
False
>>> True and True
True
>>> not (False and False)
True

Q: What are some other expressions equivalent to: \((x == 10)\) or \((x > 10)\)?

A: 

Q: Expression equivalent to \(x \in [0, 10]\)?

A: 

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5.2 Logical Operators

Q: If I have two ints, a, b, how do I test whether a is divisible by b?

A:

Q: Test whether int x is odd?

A:

>>> print_about_positivity(5)
It is True that 5 is positive.
>>> print_about_positivity(-22.3)
It is False that -22.3 is positive.
>>> print_about_positivity(0)
It is False that 0 is positive.
>>> print_all_about_sign(42)
It is True that 42 is positive.
It is False that 42 is negative.
It is False that 42 is zero.
>>>
Q: Write `print_about_positivity(number)`! (Don’t use `if`!)
   Bonus challenge: `print_all_about_sign`

A:

```python
>>> print_whether_in_closed_interval(5, 3, 1200)
It is True that 5 is in the interval [3, 1200].
```

```python
>>> print_whether_in_closed_interval(-5, -3, 1200)
It is False that -5 is in the interval [-3, 1200].
```

```python
>>> min(10, 100)
10
```

```python
>>> print_whether_in_closed_interval(23, 30, 4)
It is True that 23 is in the interval [4, 30].
```
5.3 Conditional Execution

Often, we want to execute a block of code based on the value of a boolean expression. For example, might want to print out whether the value in a variable is positive.

(On board)

```python
if x > 0:
    print('x is positive.')
```

This is known as a Conditional! Let’s break it down!

Break down:

- **Keyword**: `if`
- **Space**: `x > 0`
- **Colon**: `:`
- **Header**:

Q: Get `print_whether_in_closed_interval` to work as in the first two examples. Header: `print_whether_in_closed_interval(x, low, high)`. Bonus challenge: get it to work for the harder case, where the lower interval boundary might be last.

A:
**Def:** Compound Statement A compound statement is a statement that contains a header and a body consisting of other substatements.

There must be at least one statement inside the body of a compound statement!

As an example, let’s modify `draw_polygon` by adding a conditional (and a docstring and comments).

```
(On board)
def draw_polygon(turtle, num_sides, side):
    '''Specified turtle draws a regular polygon with num_sides sides, each of length side.'''
    if (num_sides) > 1:
        #draw the polygon!
        for i in range(num_sides):
            fd(turtle, side)
            rt(turtle, 360.0/num_sides)
    if (num_sides) <= 1:
        #print a message about not doing it
```

Notice: another colon. This means we have a compound statement!
5.3 Conditional Execution

Q: Will this run?

A:

What if we don’t know what we want to write yet?

A:

pass is a line of code that does nothing.

```python
>>> world = TurtleWorld()
>>> raphael = Turtle()
>>> draw_polygon(raphael, 5, 50)
>>> rt(raphael)
>>> pu(raphael)
>>> fd(raphael, 100)
>>> pd(raphael)
>>> draw_polystar(raphael, 7, 50)
>>> pu(raphael)
>>> fd(raphael, 100)
>>> pd(raphael)
>>> draw_polystar(raphael, 8, 50)
```
>>> better_print WHETHER_IN_CLOSED_INTERVAL(5, 0, 10)
Yes, it is!
>>> x = 13
>>> better_print WHETHER_IN_CLOSED_INTERVAL(x, -3, 3)
No, it isn’t!
>>> better_print WHETHER_IN_CLOSED_INTERVAL(10, 0, 10)
Yes, it is!

Q: Implement it! Header:

```python
def better_print WHETHER_IN_CLOSED_INTERVAL(number, lower, upper)
```

Challenge: print out better message. Example: Yes, 5 is between 0 and 10!

5.4 Alternative Execution

We are often doing one thing or something else. Trick: use else.

(On Board)
```python
if x > 0:
    print('x is positive.‘)
else:
    print('x is either negative or zero.’)
```
5.5 Nested Conditionals

Replace our implementation of `better_print WHETHER IN CLOSED INTERVAL` so that it uses `else`.

```python
>>> better_print WHETHER IN CLOSED INTERVAL(6, 10, 0)
Yes, it is!
```

```python
>>> print WHETHER MONKEY("sneasel")
sneasel isn’t a monkey!
```

```python
>>> print WHETHER MONKEY("monkey")
monkey!
```

Q: Change yours so the same things happens! Also, code up `print WHETHER MONKEY`.

5.5 Nested Conditionals

(order swapped with Chained Conditionals)

We can `nest` conditionals!
5.5 Nested Conditionals  

(On Board)

```python
if x > 0:
    print('x is positive.')
else:
    if x < 0:
        print('x is negative.')
    else:
        print('x is zero')
```

**Q:** Does the following code work?

(On Board)

```python
if x > 0:
    print('x is positive.')
if x < 0:
    print('x is negative.')
else:
    print('x is zero')
```

**Q:** Why not?

**A:**
5.6 Chained Conditionals

Alternatively, we can use `elif`. Called a *chained conditional*.

```
(On Board)
if x > 0:
    print('x is positive.')
elif x < 0:
    print('x is negative.')
else:
    print('x is zero.')
```

There can be an unlimited number of `elifs` in one conditional!

```
(On Board)
if x > 0:
    print('x is positive.')
elif x < 0:
    print('x is negative.')
elif x == 0:
    print('x is zero.')
else:
    print('x must not be a number!')
```

**Q:** What happens if I start with an `elif` instead of an `if`?

**A:**
>>> print_about_sign(13)
13 is positive.
>>> print_about_sign(-2210)
-2210 is negative.
>>> print_about_sign(5-5)
0 is zero.
>>> print_about_type(35)
35 is an integer.
>>> print_about_type('gibbon')
gibbon is a string.
>>> print_about_type([1, 2, 3])
[1, 2, 3] is a list.

Q: Write print_about_sign(number)! You may use either nested or chained conditionals! Bonus Challenge: print_about_type.

A:
Here’s some very contrived examples that tends towards Nested Conditionals:

```python
>>> print_about_integer(10)
10 is positive and not a perfect square.
>>> print_about_integer(16)
16 is positive and a perfect square.
>>> print_about_integer(-4)
-4 is negative and even.
>>> print_about_integer(-27)
-27 is negative and odd.
>>> print_about_integer_or_string('hi')
hi comes before "kyle" alphabetically.
>>> print_about_integer_or_string(35)
35 is odd.
>>> print_about_integer_or_string('zilwaukee')
zilwaukee comes after "kyle" alphabetically.
```
Q: Implement `print_about_integer`. Bonus challenge: `print_about_integer_or_string`. Hint: you can use less-than and greater-than to compare strings!

A: 

One more example. I did this one with a chained conditional:
>>> print_about_turtle('Raphael')
Raphael is rude.
>>> print_about_turtle('Donatello')
Donatello does machines.
>>> print_about_turtle('Leonardo')
Leonardo leads.
>>> print_about_turtle('Michaelangelo')
Michaelangelo is a party dude.
>>> print_about_turtle('Shredder')
Shredder is not a teenage mutant ninja turtle.
>>>
5.7 Recursion

We have functions call other functions. We can also have functions call themselves! Whoa!!!!!
5.8 Recursive Stack Diagrams  

A stack diagram will help figure out what happened!  
〈 Draw out the stack diagram for this! 〉

**Def:** *Recursion*  *Recursion* is the process of a function calling itself.  
I could write this differently
def countdown_alternative(n):
    if n <= 0:
        print('Blastoff!')
        return
    print(n)
    countdown_alternative(n-1)

>>> countdown_alternative(3)
3
2
1
Blastoff!

Q: What does return do?

A:

5.9 Infinite Recursion

def keep_going():
    print('''Let's keep going''')
    keep_going()
Q: What happens when I call keep_going()?

A: 

Q: Why?

A: 

Def: Infinite Recursion is a sequence of recursive calls that will never terminate.

Q: What if we swap the two lines in the body of keep_going?

A: 

```python
>>> keep_going_backwards()
```

You can press Ctrl + C to stop execution. Demonstrate!

Break down parts of countdown:
```python
def countdown(n):
    if n <= 0:
        print('Blastoff!')  
```
When you are writing recursive functions, make sure you have both base and recursive cases!

---

6The earliest version of this I found was at http://www.csd.uwo.ca/courses/CS2120a/class15.html, but I first saw it at https://www.reddit.com/r/ProgrammerHumor/comments/5geas6/snack_overflow/. 
Recursive Function Writing Plan: (with `countdown` as the example)

0. Write the condition for the base case. \((n \leq 0)\)
1. Write the body of the base case (`\texttt{print('Blastoff!')}\`).
2. Write the recursive \texttt{call down somewhere else}. (Do not write it in your code yet. A piece of paper off to the side is best.)

3. **Leap of Faith**: What should that recursive call do? Assume it does that!

4. Little bit of work: Write the code that uses that recursive call to solve the problem.

\begin{tabular}{|l|}
\hline
\textbf{Q:} & What is the leap of faith for `countdown`? \\
\hline
\textbf{A:} & \\
\hline
\textbf{Q:} & In `countdown`, what was the little bit of work that is done? \\
\hline
\textbf{A:} & \\
\hline
\end{tabular}
Q: Consider `countdown(3)`. What will the recursive call look like (with the value instead of the actual argument expression)?

A:

Q: What part of the output is handled by the recursive call?

A:

Q: So what is the “little bit of work” that is done in `countdown(3)`’s recursive case?

A:

Let’s do a super-simple example and go through the five-points.
>> monkeys(4)
monkey monkey monkey monkey

>> monkeys(0)

>> monkeys(2)
monkey monkey

Q: What does the header and docstring look like?

A: def monkeys(n):
    '''Prints monkey n times.'''

Q: Okay, Recursion Step 0. What is the condition for the Base Case for monkeys? Hint: think as small as makes sense.

A: When n is 0.

Q: Why not 1?

A: Because then we’re not covering the zero case. You really want to think as small as possible for the base case.
<table>
<thead>
<tr>
<th>Q:</th>
<th>So what does that code look like?</th>
</tr>
</thead>
<tbody>
<tr>
<td>A:</td>
<td>n == 0. (You could also use n &lt;= 0 to guard against negative numbers.)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q:</th>
<th>What does our code look like so far?</th>
</tr>
</thead>
</table>
|    | def monkeys(n):
|    | '''Prints monkey n times.'''
| A: | if n==0:
|    |     # Base Case
|    | else:
|    |     # Recursive Case |

<table>
<thead>
<tr>
<th>Q:</th>
<th>Great! Now on to step 1: Write the body of that base case branch. What should we do there? Hint: look at the base case example above.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A:</td>
<td>Just print a new line: print()</td>
</tr>
</tbody>
</table>
### Q:
Let’s put it all together now.

```python
def monkeys(n):
    '''Prints monkey n times.  
    
    if n==0:
        # Base Case
        print()
    else:
        # Recursive Case
```

### A:

Step 2: we need to write down the recursive call to use in the recursive case. We need to write this down somewhere else. Don’t put it in your code until later. How do we decide what the recursive call is going to do?

Well, remember that the recursive case is going to do two things:

- Do a little bit of the work hard-coded right in here, and
- Do most of the work by making the recursive call on a slightly-smaller argument.

It will definitely take a bit of trial-and-error before you’re used to choosing recursive calls, but this is a very easy example. You just want to call it on one less than n.
Q: Okay, so what does the recursive call actually look like?

A: monkeys(n-1)

Q: Okay, now let’s put that into our co-

A: No, don’t! Don’t put the recursive call into your code yet.

Q: Oh, okay. What’s part 3, then? Oh, the Leap of Faith! What does that mean we need to do?

A: We need to believe that the recursive call is going to work. In this case, that means that monkeys(n-1) does it’s supposed to. We pretend that the function is fully written and that the recursive call will work. (Even though it doesn’t.)
Q: Okay, so what does the recursive call do?

A: It prints out \texttt{monkey} \( n - 1 \) times, all on the same line, separated by spaces.

Q: Okay, step 4. Assuming the recursive call is going to work, what else do we have to do? It can help to think about an example. If \( n \) is 5, what is going to be printed by the recursive call, \texttt{monkeys(n-1)}?

A: \texttt{monkey monkey monkey monkey monkey}.

Q: Okay, so what else needs to be done?

A: We have to print \texttt{monkey} out one more time.

Q: We want to do that without printing a new line and putting a space afterwards. How can we print \texttt{monkey} and do that?

A: \texttt{print('monkey', end = ' ')}
Q: Okay, now it’s time to put it all together! Do we want to print that single monkey first, or make the recursive call first?

A: We want to print the single monkey first.

Q: Why is that?

A: Otherwise the base case will happen before we print the single monkey and the new line will happen before all the monkeys. We want that new line to be the last thing.

Q: Okay, let’s see the whole thing!

```
def monkeys(n):
    '''Prints monkey n times.'''
    if n==0:
        # Base Case
        print()
    else:
        # Recursive Case
        print('monkey', end = ' ')
        monkeys(n-1)
```
These are the kind of steps you’ll want to walk through when writing your own recursive functions.

The recursive case is often tricky! Two parts:

• Do a small amount of the work.
• Make the recursive call.

Always write the base case first. Then, if you get stuck on the recursive case, consider the case where the recursive call will call the base case. (For example, `countdown(1)`. Then think about what the “little bit of work” will be that your recursive case will do and put the two parts together. Often, this will get you close to writing your recursive case.

Example: I’m going to give the count for just this number, then trust that the recursive call will count down the rest.
```
>>> final_countdown(5)
5
4
3
2
1
Blastoff!
>>> final_countdown(20)
10
9
8
7
...
3
2
1
Blastoff!
```

**Q:** How could we implement `final_countdown`? It only counts down the last ten numbers.

**A:**
>>> count_to(10)
  1
  2
  ...
  10
Done!
>>> count_to_helper(12, 15)
  12
  13
  14
  15
Done!
>>> count_to_helper(100, 4)
Done!
>>> count_to(3)
  1
  2
  3
Done!
>>> evens_between(3, 7)
  4
  6
>>> evens_between(2, 5)
  2
  4
>>>
Q: What’s the base case for `count_to_helper`?

A: 

Q: Implement `count_to`! Hint: You’ll need to implement `count_to_helper` first. Bonus challenge: `evens_between`!

A: 

5.10 Keyboard Input

`input()` gets input while the program is running! It is a fruitful function!
```python
>>> word = input()
Monkieeeez!
>>> print(word)
Monkieeeez!
```

You can add text and ask a question!

```python
>>> name = input("What is your name?")
What is your name? Kyle Burke
>>> greet(name)
Hi, Kyle Burke!
```

Q: What’s the problem here?

A: One solution: add more spaces.

```python
>>> name = input("What is your name? ")
What is your name? Kyle Burke
>>> greet(name)
Hi, Kyle Burke!
```

Another solution: add a line break!
>>> name = input("What is your name? \n")
What is your name?
Kyle Burke
>>> greet(name)
Hi, Kyle Burke!

Let's add input to the body of a function!

>>> greet_prompt()
Whom would you like to greet?
Steve
Hi, Steve!

Implement it! Header:

Q:

A:
5.10 Keyboard Input

Implement it! Header:

Q:

```python
def is_between_prompt(lower, upper):
    pass
```

Hint: `input` always returns a string! Bonus Challenge: make it work so it always uses the min of inputs as lower and max as upper.

A:
>>> is_between_maybe_keepasking(-6, 3)
Which number would you like to test?
0
Yes, it is!
Would you like to test another number?
yes
Which number would you like to test?
24
No, it isn't!
Would you like to test another number?
no
>>> is_between_keepasking(-1, 5)
Which number would you like to test?
0
Yes, it is!
Which number would you like to test?
24
No, it isn't!
...

...
6 FRUITFUL FUNCTIONS

Q: Implement it! Header:

```python
def is_between_keep_asking(lower, upper):
```

Challenge: `is_between_maybe_keep_asking(lower, upper)`

A:

6 Fruitful Functions

6.1 Return Values

Alright, it’s time to write fruitful functions! Now we will write functions that return a value! We’ve already seen:
What if we want a function like `math.sin` that returns a value when called? We will use the keyword `return`.

```python
def area_of_circle(radius):
    '''Returns the area of a circle with the specified radius.'''
    area = math.pi * (radius ** 2)
    return area

>>> area = area_of_circle(3)
>>> print(area)
28.27433
>>> print(area_of_circle(5))
78.539...
```

Q: What does the `return area` line do?

A:
Q: What do you think return alone does?

A: 

6.2 Incremental Development

6.3 Composition

I could use this to calculate the volume of a cylinder with radius 10 and height 7!

\[ \text{Draw a picture of cylinder and describe formula for the volume.} \]

```python
>>> circle_area = area_of_circle(10)
>>> volume = circle_area * 7
>>> print(volume)
2199.11
```

Notice: keyword `return`, followed by a value.

Q: How might we write the body of `area_of_circle` in one line?

A: 

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6.3 Composition

6 FRUITFUL FUNCTIONS

```python
>>> area = area_of_triangle(base = 4, height = 5)
>>> print(area)
10.0
>>> trapezoid_area = area_of_trapezoid(top = 4, base = 6, height = 3)
>>> print(trapezoid_area)
15.0
```

Implement it! Header:

Q:

area_of_triangle(base, height):

Challenge:

area_of_trapezoid(top, base, height)

A:
>>> volume = volume_of_cylinder(radius = 5, height = 7)
>>> print(volume)
549.7787143782139
>>> cone_volume = volume_of_cone(base_radius = 7, height = 18)
>>> print(cone_volume)
42.0

〈 Draw a picture! 〉

<table>
<thead>
<tr>
<th>Implement it! Header:</th>
</tr>
</thead>
</table>

**Q:**

```
def volume_of_cylinder(radius, height):
```

Hint: use `area_of_circle`
Challenge: `volume_of_cone`

**A:**
>>> number = absolute_value(4)
>>> number
4
>>> weight = absolute_value(-27)
>>> print(weight)
27

Write this! (There is a function that does it for you in the math package; I want you to try writing it on your own!)

Q:

```python
def absolute_value(number):
```

Challenge: after you get it to work, do in one line?

A:

You have to be careful! Mine doesn’t work for zero!

```python
>>> print(absolute_value(0))
None
```

6.4 Boolean Functions

Can write Boolean Fruitful functions as well!
>>> parity = is_even(3)
>>> print(parity)
False
>>> is_even(222)
True
>>> is_square(4)
True
>>> is_square(5)
False

Implement it! Header:

Q:

```python
def is_even(number):
    # Hint: use modulus operator!
    # Challenge: write in one line. Bigger Challenge: write
    is_square(number)
```

A:
6.4 Boolean Functions

```python
>>> parity = is_odd(3)
>>> print(parity)
True
>>> is_odd(222)
False
TODO: needs a bonus challenge!
```

Q: Implement `def is_odd(number):` Bonus challenge: composition — call `is_even`!

A:
>>> between = is_between(5, 10)
Which number would you like to test?
8
>>> print(between)
True
>>> test_value = is_between(5, 10)
Which number would you like to test?
265
>>> if test_value:
    print("That’s crazy!")
else:
    print("That’s what I expected.")
...
That’s what I expected
>>> is_between(10, 5)
Which number would you like to test?
7
True
>>>
Implement it! Header:

Q:

```python
def is_between(lower, upper):
```

Bonus Challenge: get it to work so that the first doesn’t have to be the lower bound.

A:

Let’s do a tough one! Let’s write a function that calculates the area of a rectangle given two corners.

```python
>>> area_of_rectangle_between_points(1, 5, 3, 1)
8
>>> area = area_of_rectangle_between_points(4, 6, 6, 4)
>>> print(area)
4
>>> area_of_triangle_in_points(0, 0, -3, 4, -8.5, 3)
12.5
```
Implement it! Header:

```python
def area_of_rectangle_between_points(x0, y0, x1, y1):
```

Hint: give docstring. Bonus challenge: `area_of_triangle_in_points`

Q: Could we rewrite this so that it doesn’t matter which point is which, so long as they are in opposite corners?

A:
Q: What do we need to do now?

A:

6.4.1 Testing Fruitful Functions

Q: How were we testing functions that printed instead of returned?

A:

```python
print('Testing greet(Elman):')
print('Should output: Hi, Elman!')
print('Actual output: ', end = '')
greet('Elman')
```
Q: Can we do the same sort of thing with fruitful functions?

Yes!

```python
print('Testing absolute_value(35):')
print('Should output: 35')
print('Actual output:', absolute_value(35))
print('')
print('Testing absolute_value(-3012):')
print('Should output: 3012')
print('Actual output:', absolute_value(-3012))
print('')
print('Testing absolute_value(0):')
print('Should output: 0')
print('Actual output:', absolute_value(0))
```

A: Absolutely!

Q: Can we do better?

A: Absolutely!
Q: Rewrite the three tests so each only prints one line instead of three. Hint: use conditionals.

A: 

Q: Do you think it’s more important to print out a message when a function works or when it’s incorrect?
Q: Hmm... Think back to one of our software design techniques. Which one could we use to improve our code here?

A: There’s lots of repeated code, so... encapsulation!

Okay then, let’s wrap that conditional up in a function. (Recall that my `absolute_value` function is broken for 0.)

```python
>>> test_function('absolute_value',
    absolute_value(35), 35)
>>> test_function('absolute_value',
    absolute_value(-3012), 3012)
>>> test_function('absolute_value',
    absolute_value(0), 0)
Error while testing the absolute_value function! Returned None instead of 0
```
Q: Write test_function(name, result, goal)!

A:

6.5 Fruitful Recursion

Let’s combine fruitful functions and recursion to perform calculations! What about factorial?

Q: How does factorial work?

\[ n! = \begin{cases} 
  1 & , n = 0 \\
  n \times ((n - 1)!) & , n > 0
\end{cases} \]
>>> x = factorial(0)
>>> print(x)
1
>>> y = factorial(4)
>>> print(y)
24
>>> factorial(10)
...

Implement it! This one’s hard! Header:

Q:

```python
def factorial(integer):
    # Hint: Base case first!
    # Hint: Two parts to recursive case!
```

A:

( Draw a stack diagram for >>> factorial(5)
120. )
6.6 Leap of Faith

Leap of faith is more important with fruitful recursion!
Expect the recursive call to work!
Moving away from print, returning instead! But, print is still very useful in debugging!

Example: add a print statement to factorial:

```python
print("Result of recursive call: " + str(recursive_result))
```

I have an even more comprehensive version with more prints.

```
>>> x = factorial_with_prints(4)
Calculating 4 recursively...
Calculating 3 recursively...
Calculating 2 recursively...
Calculating 1 recursively...
At the basecase: 0 = 1
1 is: 1 times 1 = 1
2 is: 2 times 1 = 2
3 is: 3 times 2 = 6
4 is: 4 times 6 = 24
>>> print(x)
24
```

If something were going wrong, I could tell here, possibly without even looking at my code! Here's an example:
6.7 Example: Fibonacci

```python
>>> y = factorial_wrong(4)
Calculating 4 recursively...
Calculating 3 recursively...
Calculating 2 recursively...
Calculating 1 recursively...
At the basecase: 0 = 1
1 is: 1 times 1 = 2
2 is: 2 times 2 = 4
3 is: 3 times 4 = 7
4 is: 4 times 7 = 11
```  
```python
>>> print(y)
11
```

Notice, you can tell what I’m doing wrong without seeing this code!

6.7 Example: Fibonacci

**Q:** What are the first five numbers in the Fibonacci sequence?

**A:**

**Q:** How do you calculate the next number from the previous two?

**A:**
Draw out a bunch of the sequence: 0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, ...

```python
>>> f = fibonacci(0)
>>> print(f)
0
>>> print(fibonacci(0), fibonacci(1),
    fibonacci(2), fibonacci(3), fibonacci(4))
0 1 1 2 3
>>> fibonacci(10)
55
>>> fibonacci(20)
6765
>>> fibonacci(40) #Wait for it...
102334155
>>> print(tribonacci(0), tribonacci(1),
    tribonacci(2), tribonacci(3), tribonacci(4),
    tribonacci(5))
0 1 1 2 4 7
>>> x = tribonacci(10)
>>> print(x)
149
```
Implement it! Again, hard! Header:

**Q:**

def fibonacci(index):

Hint: Two base cases!

Hint: Two recursive calls!

**A:**

```
>>> fibonacci(5)
5
```

Notice this goes pretty slowly... I have a faster version!

```
>>> fast_fibonacci(40)
102334155
>>> fast_fibonacci(100)
354224848179261915075L
```

I'm not going to ask you to do this, but I did it using a helper function that keeps track of two values at a time. You can return two values using tuples, which we will learn about in a future chapter.
6.7 Example: Fibonacci

FRUITFUL FUNCTIONS

Explain Triangular\(^7\) and Tetrahedral numbers\(^8\)!

>>> triangular_number(3)
6
>>> triangular_number(5)
15
>>> triangular_number(100)
5050
>>> tetrahedral_number(2)
4
>>> tetrahedral_number(5)
35

Q: Implement `triangular_number`! (Do it recursively!) Bonus challenge: `tetrahedral_number`.

A:

\(^7\)More info about Triangular numbers: https://en.wikipedia.org/wiki/Triangular_number.

\(^8\)More info about Tetrahedral numbers: https://en.wikipedia.org/wiki/Tetrahedral_number
6.8 Checking Types and Guardians

Q: What happens if I try to call\n\[ \text{fibonacci(-1)} \]
with the code we’ve written?

A: Let’s see what happens when I run the code I’ve written...

```python
>>> fibonacci(-1)
Fibonacci is not defined for negative numbers!
```

Q: Wow! How did I make that happen?

A: I added a guardian, a test in a function to handle inappropriate inputs. Here’s my guardian:

```python
if index < 0:
    print("Fibonacci is not defined for negative numbers!")
elif ...
```
Q: There’s a name for the practice of protecting code from unintended situations. What is it?

A: Defensive Programming

Q: What else might work to break fibonacci?

A: A float! Let’s try it out!

```python
>>> fibonacci(2.5)
fibonacci is only defined for integers!
>>> fibonacci("monkeyface")
fibonacci is only defined for integers!
```

Whoa! How can we make that work? Use: `isinstance`!

```python
>>> is_int = isinstance(5, int)
>>> is_int
True
>>> not_int = isinstance("monkey", int)
>>> print(not_int)
False
>>> isinstance(7, float)
False
>>> isinstance("apricot", str)
True
```
Implement this guardian! Bonus challenge: implement it to also cover the following cases:

```python
>>> fibonacci(10.0)
55
```

Q: Does the order of these matter?

A:
Q: What is being returned when the body of these guardians is run?

A:

We can add returns to unnest rest of the function:

(On Board)
if not isinstance(index, int):
    print("Fibonacci is only defined for integers!")
    return
elif index < 0:
    print("Fibonacci is not defined for negative numbers!")
    return
...rest of the body...

Q: Do we think that checking whether a value is an integer is something we might want to do often?

A: Maybe, yeah!
```python
>>> is_integer(53)
True
>>> x = is_integer('monkey')
>>> print(x)
False
>>> y = is_integer(-13.0)
>>> print(y)
True
>>> z = is_natural(-13)
>>> z
False
>>> is_natural(10)
True
>>> is_natural(10.0)
True
```

**Q:** Implement it! Header:
```python
def is_integer(value):
```

**A:**
```python
def is_natural(value):
```
Q: What happens if you call `fibonacci` on a boolean value? It should break, right?

Crazy stuff happens!

```python
>>> fibonacci(True)
1 (Yours says True, because of base case(s).)
```

```python
>>> fibonacci(False)
0 (False)
```

A: Python treats booleans as integers! Here are some more crazy cases!

```python
>>> False == 0
True
```

```python
>>> True == 1
True
```

```python
>>> 5 + True
6
```

7 Iteration

We’ve learned how to write code to answer any question a computer can answer. Are we done? No! There
are lots more tools that can make things easier.

7.1 Multiple Assignment

Something weird:

```python
>>> x = 5
>>> print(x)
5
>>> x = 100
>>> print(x)
100
```

*Multiple Assignment*: Same variable, but different values at different times!

```python
>>> x = 5
>>> x = x + 1
>>> print(x)
6
```

7.2 Updating Variables

*Variable Updating*: new value of the variable depends on the old value.

```python
>>> for i in range(10):
    x = x + 1
...
>>> print(x)
16
```
Def: **Increment** Updating a variable by adding 1.
Def: **Decrement** Updating a variable by subtracting 1.

One of the most important things we use computers for is to perform repetitive calculations. They’re good at it; we’re not.

### 7.3 **while**

**Def: Iteration** Repetitive calculation is called iteration.

```python
>>> def countdown_alternative(n):
    while n > 0:
        print(n)
        n = n-1
        print("Blastoff!")
...

Q: What will happen when I call: `countdown_alternative`?
7.3 while

```python
>>> countdown_alternative(5)
5
4
3
2
1
Blastoff!
```

**Def:** *Loop* Loops back through a block of code multiple times.

while is a combination of if and for.

The body of a loop should change variables so that eventually the condition becomes false... otherwise: *infinite loop!*

```python
>>> x = 7
>>> y = 0
>>> while x > 5:
    y = y + 1
    print("y = ", y)
... (Don’t hit enter yet!)
```

**Q:** What will happen when I hit enter?

**A:**

(Do it!)
Q: Where is there an infinite loop in your everyday life? Hint: something you might do every morning. (Maybe not now that you’re in college...)

A:

Sometimes it’s not clear whether there’s an infinite loop. It’s not obvious whether a program will finish, or terminate. Look at page 65\(^9\): `sequence(n)`.

```python
def sequence(n):
    '''Prints out the Collatz sequence starting with n.'''
    while n != 1:
        print(n, end = " ")
        if n % 2 == 0:
            #n is even
            n = n / 2
        else:
            #n is odd
            n = n*3 + 1

Q: Type it in! Will it always terminate?

```python
>>> sequence(3)
3 10 5 16 8 4 2
```

\(^9\)http://greenteapress.com/thinkpython2/thinkpython2.pdf#page=87

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Q: Is there a positive integer for \( x \) for which this doesn’t terminate?

A: 

```python
>>> print_monkeys(2)
monkey
monkey

>>> print_monkeys(4)
monkey
monkey
monkey
monkey

>>> print_monkey_mountain(4)
monkey
monkeymonkey
monkeymonkeymonkey
monkeymonkeymonkeymonkey
```

TODO: switch to monkeys

Implement it using iteration! Hint: use a `while` loop based on `n`. Bonus challenge:

```python
def print_monkey_mountain(n):
    # code
```

Q: Def print_monkeys(n):

Hint: use a `while` loop based on `n`.
>>> print_fibonacci_sequence(5)
0 1 1 2 3
>>> print_fibonacci_sequence(30)
0 1 1 2 3 5 8 13 21 34 ...
>>> fast_print_fibonacci_sequence(100)
... much faster!...

Q: Implement it! Header:
   def print_fibonacci_sequence(n):
   Bonus challenge: fast_print_fibonacci_sequence

A:
>>> multiply(3, 21)
63
>>> x = multiply(4, 5)
>>> print(x)
20
>>> multiply(0, 5)
0
>>> exponentiate(57, 0)
1
>>> big_number = exponentiate(5, 3)
>>> print(big_number)
125

Q:
Implement `multiply` without using `*`. Bonus challenge: implement `exponentiate` without using `**`. Hint: give the first line double hint: give the last line

A:
7.4 break

We can also use break to escape a loop anywhere instead of only at the top. Try out example on bottom of page 66\(^{10}\). I encapsulated the example into a function:

```python
>>> input_break_test()
> monkey
monkey
> done
All done!
>>> 
```

7.5 Square Roots

TODO: I need a bonus challenge problem for this section. Taylor expansion or something like that?

Calculating square roots can be hard. Let’s pretend we didn’t have a nice operation to do it. There is a method to improve guesses: Newton’s Method.

If you have a guess for \( \sqrt{a} \), there is a way to improve that guess dramatically. Start with estimate: \( x \). Then a better estimate is: \( \frac{x + \frac{a}{x}}{2} \).

Let’s test this out in Python.

\(^{10}\)http://greenteapress.com/thinkpython2/thinkpython2.pdf#page=88
```python
>>> a = 4.0
>>> guess = 3.0
>>> guess ** 2
9.0
>>> better_guess = (guess + a/guess)/2
>>> print(better_guess)
2.16666666666665
>>> print(better_guess ** 2)
????
```

That is much closer to 4 than 9 was!

**Q:** Can we do better?

**A:**

```python
>>> guess = better_guess
>>> better_guess = (guess + a/guess)/2
>>> print(better_guess)
2.00641025641
>>> print(better_guess ** 2)
```

Again!
7.5 Square Roots

>>> guess = better_guess
>>> better_guess = (guess + a/guess)/2
>>> print(better_guess ** 2)
??
>>> guess = better_guess
>>> better_guess = (guess + a/guess)/2
>>> print(better_guess ** 2)
??

Q: It could take a while to get to the correct answer. How do we know when we’re there?

A:

>>> guess = better_guess
>>> better_guess = (guess + a/guess)/2
>>> print(better_guess ** 2)
4.0
>>> print(better_guess)
2.0
>>> guess = better_guess
>>> better_guess = (guess + a/guess)/2
>>> print(better_guess)
2.0
>>> square_root_from_guess(4.0, 3.0)
Given guess: 3.0
Better guess: 2.1666666666666667
Better guess: ...
Better guess: 2.0
Better guess: 2.0
Best guess: 2.0
2.0
>>> root = square_root_from_guess(16.0, 10.0)
Given guess: 10.0
Better guess: ...
Best guess: 4.0
>>> print(root)
4.0

Implement it! Header:

Q:

def square_root_from_guess(base, guess):

(Don’t use math.sqrt!)

A:

This can be a bit dangerous! What if the code
doesn’t do a good job approximating and keeps being close, but not exact?

```python
>>> root = square_root_from_guess(6.0, 3.0)
Given guess:  3.0
Better guess: ...
...
(infinite loop. Mine works, but theirs won’t.)

>>> root = math.sqrt(6.0)
>>> root ** 2
5.999999999999999991
```

**Q:** How can we fix `square_root_from_guess` to make this work?

**A:**
```python
def square_root_from_guess(base, guess, epsilon):
    print('Base guess:', guess)
    while abs(base - (guess ** 2)) > epsilon:
        better_guess = (guess + base/guess)/2
        print('Better Guess:', better_guess)
        guess = better_guess
    return better_guess
```

Notice that mine works whether or not I specify the \texttt{epsilon} parameter:

```python
>>> square_root_from_guess(4.0, 3.0)
2.0
>>> square_root_from_guess(4.0, 3.0, epsilon = .001)
2.0001something
```

**Q:** How did I do this?

**A:**
Q: Challenge: change **epsilon** to be a default parameter.

A:

Q: What’s an important part of default parameters?

A: Can’t have a non-default param after default ones. All defaults at the end of the param list.

```python
>>> my_square_root(15)
3.872983346207417
>>> root = my_square_root(13)
>>> print(root)
3.6055512754639896
>>> root ** 2
13.000000000000002
```
Challenge: write `my_square_root`. Hint: two parts:

Q:
- Remove scaffolding.
- Add the wrapper function.

A:

Q: What is this called, when you have a function that just calls another function with more parameters?

A: `Worker-Wrapper` programming pattern.

7.6 Algorithms

Newton’s method is an example of an algorithm.

Def: **algorithm** A mechanical process for solving a category of problems.

You already know lots of algorithms!
- how to add two numbers with any amount of digits
- how to count the number of branches in a pile of sticks

Some things are not algorithmic: adding `single-digit`
numbers. You probably memorized all combinations!
Carrying out algorithm doesn’t require intelligence. Just follow steps.
Creating algorithm does! Central to the art of programming!

Q: How do we approximate \( \pi \)?

A: Algorithms! Example: Gauss-Legendre Algorithm

More info: https://en.wikipedia.org/wiki/Gauss%E2%80%93Legendre_algorithm

Q: How do we use these formulas to create an algorithm?

Start with:
- \( a_0 = 1 \)
- \( b_0 = 1/\sqrt{2} \)
- \( t_0 = 1/4 \)
- \( p_0 = 1 \)

Our first approximation is:

\[
\pi \approx \frac{(a_0 + b_0)^2}{4t_0} \approx 2.914
\]
That’s not too great. How can we improve it? Say we have $a_k$, $b_k$, $t_k$, and $p_k$, and they provide an approximation using the same formula:

$$\frac{(a_k + b_k)^2}{4t_k}$$

How can we find the next round: $a_{k+1}$, $b_{k+1}$, $t_{k+1}$, and $p_{k+1}$ that will produce a better approximation? (I’m not expecting you to know this without looking up the Wikipedia page for Gauss-Legendre.)

**Q:**

**A:**

- $a_{k+1} = (a_k + b_k)/2$
- $b_{k+1} = \sqrt{a_k \cdot b_k}$
- $t_{k+1} = t_k - p_k(a_k - a_{k+1})^2$
- $p_{k+1} = 2p_k$

TODO: talk about the rate of the number of correct digits.
>>> bad_pi = my_pi(0)
>>> print(bad_pi)
2.914213562373095
>>> my_pi(1)
3.1405792505221686
>>> my_pi(2)
3.141592646213543
>>> my_pi(3)
3.141592653589794
>>> my_pi(10)
...

7.6 Algorithms

Page 161 © 2020 Kyle Burke 🌑
Implement my_pi! Hint: outside the while loop I created variables a, b, t, and p. Inside, I created variables for the next round: a_next, b_next, etc. After setting those four new variables, I reset the original 4. Bonus challenge: Look up another π approximation to use!
7.7 Debugging

Debugging! If I have a program with 100 lines that has a semantic error, but I don’t know where the error is occurring, I have a few options to debug, using print:

- Put a bunch of print statements inbetween as many lines as possible (100?)
- Put just one print statement in and see if the program makes sense up to that point.

Q: If I do that second option, where should that print statement go?

A: Rules out biggest part of code where first error is occurring!

8 Strings

We did something weird with `is_palindrome` in a recent project...

```python
>>> fruit = "banana"
>>> letter = fruit[1]
```
8.1 Strings as Sequences

Q: What just happened? What are those brackets?
A: Consider string as a sequence of characters. Can use brackets to access individual letters. Expression in brackets: \textit{index}. Indicates which character you want!

```python
>>> print(letter)
a
```

Q: Why did that happen?
A:

```python
>>> fruit[0]
a
```

“Zeroeth”, “Oneth”, “Twoeth”, “Threeeth”, “Foureth”, ...

Page 164 © 2020 Kyle Burke
Q: What will happen if I try to use a float as the index?

A:

```python
>>> fruit[3.14]
Type Error!
```

8.2 len

```python
>>> length = len(fruit)
>>> print(length)
6
```

Q: What will happen if I try

```python
last = fruit[length]
```

?

A:

```python
>>> last = fruit[length]
IndexError!
```

Since we started with 0, 6 is too high! Two options.
>>> last = fruit[length - 1]
>>> print(last)
a
>>> fruit[-1]
'a'

Q: Which 'a' is this?

A:

Can either index from [0, length-1] or [-length, -1].

>>> middle_char('apple')
'p'
>>> char = middle_char('banana')
>>> print(char)
n
>>> x = first_middle_last('apple')
>>> print(x)
'ape'
Q: Write `middle_char`! Bonus challenge: `first_middle_last`.

A:

```python
>>> first_characters('beluga', 3)
'bel'
>>> prefix = first_characters('onomatopoeia', 6)
>>> print(prefix)
onomat
>>> first_characters('skullduggery', 20)
skullduggery
>>> last_characters('banana', 5)
'anana'
```
Q: Code up first_characters. Bonus challenge: last_characters. (Don’t give up too much in last_characters; it’s a project problem!)

A:

```python
>>> extend_string('beluga', 15)
'belugabelugabelugabel'
>>> s = extend_string('giraffe', 4)
>>> print(s)
gira
>>> x = pongify("banana")
>>> print(x)
banananaananabbananana
>>> pongify('ape')
'aapeaape'
```
Q: Write `extend_string`! Hint: I used recursion, though you can also do iteration. Bonus challenge: `pongify`.

A:

```python
>>> middle_chars("antelope hoard", 6)
'lope h'
>>> middle = middle_chars("terrasque", 3)
>>> print('middle:', middle)
middle: ras
```
Q: Code up `middle_chars`. TODO: make a bonus challenge for this.

A:

8.3 Traversing with for

Q: What if we want to do something to each letter in a string?
>>> index = 0
>>> fruit = 'banana'
>>> while index < len(fruit):
    character = fruit[index]
    print(character)
    index = index + 1

b
a
n
a
a

This loop traverses the string, printing each letter.

Def: traverse To visit each element in a data collection.

>>> forward_print("monkey")
m
o
n
k
e
y
8.3 Traversing with for

Implement it! Header:

Q:

```python
def forward_print(string):
    print(string)
```

Hint: encapsulate the previous code.

```python
>>> forward_print("monkey")
y e k n o m
>>> backward_print("monkey")
y e k n o m
>>> primate = "primeape"
>>> backward_print(primate)
e ... p
```
8.3 Traversing with for

**Q:**

Implement it! Header:

```python
def backward_print(string)
```

**A:**

This sort of thing happens a lot, so Python has a way to write it more simply.

```python
>>> animal = "mankey"
>>> for character in animal:
...     print(character)
...     
m
a
n
k
e
y
```

Whoa! for without range!
Q: How does this work?

A:

Q: Rewrite `forward_print` using a for loop!

A:
Which for loop is the following while loop equivalent to?

```python
index = 0
while index < len(y):
    x = y[index]
    A
    B
    : Q
    index += 1
```

A:

There are even more uses of for, which we will see soon!

Look at the example on page 73\(^\text{12}\): Make Way for Ducklings!
I encapsulated this into a function!

\(^\text{12}\text{http://greenteapress.com/thinkpython2/thinkpython2.pdf#page=95}\)
8.3 Traversing with for

```python
>>> print_duckling_names('JKLMNOPQ')
Jack
Kack
Lack
Mack
Nack
Ouack
Pack
Quack
>>> print_duckling_names('ABCDEFGHIJKLMNOPQRSTUVWXYZ')
...```

Q: Implement it! Header: `print_duckling_names(prefixes)`. It’s okay if the u’s don’t show up. Bonus challenge: get the u’s to print after A, O, and Q.

A:
>>> has_vowels('onomatopoeia')
True
>>> b = has_vowels('styx')
>>> if not b:
...    print('crazy!')
crazy!
>>> has_all_vowels('beautiful')
False
>>> has_all_vowels('beautifool')
True

Q: Implement has_vowels(string). Bonus challenge: has_all_vowels, which is quite tricky with what we’ve learned so far!

A:
```python
>>> vowels = just_vowels('Sheep go to Heaven')
>>> print(vowels)
eeooeae
>>> just_vowels('onomatopoeia')
'ooaooeia'
>>> just_vowels('styx fly')
'

>>> vowels_then_consonants('hi there')
'ieehthr'
```

Q: Implement `just_vowels`. Hint: I put a for loop inside another for loop! (There’s another way to do it, but not with the tools we have yet.) Bonus challenge: `vowels_then_consonants`.

A:

8.4 String Slices

Sometimes we want to look at just a piece of a string!
8.4 String Slices

```python
>>> word = 'smiles'
>>> subword = word[0:5]
>>> print(subword)
smile
>>> subsubword = word[1:5]
>>> print(subsubword)
mile
>>> print(word[1:5])
mile
>>> print('smiles'[1:5])
mile
```

...string[n:m] means the chunk or slice of the string from (and including) the nth character to (but not including) the mth character.

Helpful: consider the indices occurring between characters.

TODO: draw picture similar to page 73\(^{13}\), but using 'monkey'.

```python
>>> animal = "monkey"
>>> print(animal[2:5])
nke
```

Q: What is the length of slice: \texttt{string[n:m]}? 

A: 

\(^{13}\)http://greenteapress.com/thinkpython2/thinkpython2.pdf#page=95
>>> food = 'hamburger'
>>> food[i1:i2]
'urge'

Q: I set i1, i2 prior to class. What are their values?

A:

>>> animal = 'monkey'
>>> animal[i3:i4]
'monk'
>>> animal[i5:i6]
'key'

Q: What about i3, i4, i5, i6?

A:

We can actually drop the indices for the last two!

>>> print(animal[:4])
monk
>>> print(animal[3:])
key
8.4 String Slices

What will happen with

Q: >>> print(animal[:])

A:

What will happen with

Q: >>> animal[4:4]

A:

What about

Q: >>> animal[4:3]

A:
```python
>>> for i in range(4):
...    print('i:', i)
...
i: 0
i: 1
i: 2
i: 3

```
8.4 String Slices

Implement it! Header:

Q:

```
print_start_slices_of(string):
```

Hint: use a loop!

Bonus challenge: `print_end_slices_of`

A:

```
>>> starts_with('mewtwo', 'mew')
True
>>> starts_with('blastoise', 'blast')
True
>>> nope = starts_with('pikachu', 'pichu')
>>> print(nope)
False
>>> starts_with('abra', 'abra')
True
>>> starts_with('abra', 'abrakadabra')
False
>>> ends_with('mankey', 'man')
False
>>> ends_with('mankey', 'key')
True
```
Q: Implement `starts_with(string, prefix)` Hint: can use a loop or slices. Bonus Challenge: `ends_with`.

A:

8.5 Strings are Immutable

Strings are immutable!

```python
>>> greeting = 'Hi, Stevey!
>>> greeting[9] = 'n'
TypeError: ....
```

Q: Why did that happen?

A: You’d have to create a new string.
>>> new_greeting = greeting[:9] + 'n' + greeting[10:]
>>> print(new_greeting)
Hi, Steven!
>>> print(greeting)
Hi, Stevey!

8.6 String Searching

Add find to your code, from page 74:

(On Board)
def find(word, letter):
    LEAVE SPACE FOR DOCSTRING
    index = 0
    while index < len(word):
        if word[index] == letter:
            return index
        index += 1
    return -1

>>> find('abrakadabra', 'b')
1

Q: What is a good docstring for find?

A:
>>> last_index = find_last('abracadabra', 'a')
>>> print(last_index)
10
>>> find_last('monkey', 'z')
-1
>>> index = find_substring('charizard', 'riza')
>>> print(index)
3

Q: Write `find_last`! Hint: I wrote a solution that searches left-to-right. Bonus challenge: `find_substring`.

A:
8.7 Counting

(On Board)
def count(word, character):
    LEAVE SPACE FOR DOCSTRING LATER!
    count = 0
    for letter in word:
        if letter == character:
            count += 1
    return count

>>> count('abrakadabra', 'b')
2

Q: What would be a good docstring for count?

A:

>>> m = max_count('monkey')
>>> print(m)
1
>>> max_count('abrakadabra')
5
>>> char = most_frequent_character('abrakadabra')
>>> print(char)
a
8.8 String Methods

Q: Try to write max_count(string). Bonus challenge: most_frequent_character.

A:

```python
>>> word = 'monkey'
>>> new_word = word.upper()
>>> print(new_word)
MONKEY
>>> print(word)
monkey
```

upper is a method for strings.

**Def:** method A method is like a function, but specific to a data type.

The notation is similar to a function.

Idea: take the first argument, and move it to come
8.8  String Methods

infront of the function name. Use dot notation and you have a method!

```python
>>> word = 'abrakadabra'
>>> index = word.find('r')
>>> print(index)
2
```

Other types also have methods. We will learn how to use more, then later write our own!

To see all the string methods, type: ```>>> help(str)```. Here are some examples:
```python
>>> x = 'banana'.center(12)
>>> x
' banana '
>>> y = 'hi every monkey man!'
>>> z = y.title()
>>> z
'Hi Every Monkey Man!'
>>> z.replace('M', 'D')
'Hi Every Donkey Dan!'
>>> z.upper()
'HI EVERY MONKEY MAN!'
>>> to_fancy_title("monkey")
'~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ Monkey
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~'
>>> to_fancy_title("monkeys are awesome")
'~~~~~~~~~~~~~~~~~~~~~~~~ Monkeys Are
Awesome ~~~~~~~~~~~~~~~~~~~~'
>>> cameled = snake_to_camel('snake_monkey')
>>> print(cameled)
snakeMonkey
>>> snake_to_camel('snake_monkey_banana_bear')
'snakeMonkeyBananaBear'
```

A: We can use in to find substrings!

```python
>>> 'Tea' in 'Team'
True
>>> 'I' in 'Team'
False
>>> 'me' in 'Team'
False
```

We’ve used in in for loops, but that use is a bit different.

Code up in_both from page 76\(^\text{15}\):

\(^{15}\text{http://greenteapress.com/thinkpython2/thinkpython2.pdf#page=98}\)
(On Board):
def in_both(string_0, string_1):
    for letter in string_0:
        if letter in string_1:
            print(letter)

>>> in_both('apples', 'oranges')
a
e
s

>>> in_both('love', 'hate')
e

Notice: in is used in two very different ways here!

• for letter in string_0: - Here, in is used with a for-loop for iteration.

• if letter in string_1: - Here, in is used to test inclusion. This part with in evaluates to a boolean.
Q:
Change `in_both` to be fruitful instead!

```python
>>> x = in_both_f('apples', 'oranges')
>>> x
'aes'
>>> x = in_both_f('bananas', 'apples')
>>> x
'aaas'
>>> in_both_no_repeats('bananas', 'apples')
'as'
```

Bonus Challenge: change `in_both` to work so that it doesn’t include duplicates.

A:
>>> in_all_three('apples', 'oranges', 'pears')
'aes'
>>> in_all_three('apples', 'oranges', 'bananas')
'as'
>>> in_all_three('bananas', 'oranges', 'apples')
'aaas'

Implement it! Header:

Q:

\[
\text{in\_all\_three(word0, word1, word2)}:
\]

Bonus challenge: get rid of repeats!

A:
>>> common = in_two_of_three('apples', 'oranges', 'pears')
>>> print('common:', common)
common: appesr
>>> in_two_of_three('monkey', 'banana', 'apple')
'neaaa'

Q: Implement it! Header: in_two_of_three(word0, word1, word2): Bonus challenge: get rid of repeats!

A: 
8.10 String Comparisons

We have used == with strings. What about other comparators?

```python
>>> 'apple' < 'banana'
True
>>> ''horse'' < ''monkey''
True
>>> ''orangutan'' < ''dolphin''
False
>>> 'monkey' < 'gorilla'
False
>>> ''monkey'' < ''monkey
False
>>> ''monkey'' <= ''monkey''
True
```

Q: What does < mean with strings?

A:

```python
>>> 'apple' < 'Apple'
False
>>> 'Horse' < 'apple'
True
```
Q: What does this mean?

A:

```python
>>> compare_to_banana('monkey')
Your word, monkey, comes after banana.
>>> compare_to_banana('apple')
Your word, apple, comes before banana.
>>> compare_to_banana('banana')
All right, bananas!
>>> compare_to_banana('Banana')
Your word, Banana, comes before banana.
```
Implement it! Header:

Q:

```python
def compare_to_banana(word):
```

A:

```python
>>> first = earlier_string('abra', 'kadabra')
>>> print(first)
abra
>>> earlier_string('apple', 'abba')
'abba'
>>> strings_in_order('bulbasaur', 'ivysaur', 'venusaur')
True
>>> strings_in_order('abra', 'kadabra', 'alakazam')
False
```
Q: Implement `earlier_string(string_0, string_1)`. Bonus challenge: `strings_in_order`.

A:

Q: When might this be useful?

A:

Here’s another one similar to older stuff that you can improve with comparisons.
```python
>>> repeated = repeated_characters('Sheep go to Heaven')
>>> print(repeated)
'eoee'
>>> repeated_characters('eevee')
'eee'
>>> repeated_characters('four')
''
>>> repeated_characters_better('Sheep go to Heaven')
'e o'
>>> repeated_characters_best('Sheep go to Heaven')
'eo'
```

**Q:** What's the difference between the better and best versions?

**A:** best returns a string with the characters in lexicographical order.
Q: Implement repeated_characters(string). Bonus challenge: get rid of repeats.

A:

9 Files and Words

If we want a bunch of words, it may be easier to read those from a file.

9.1 Reading a File

 Ask students to visit: the class schedule, find words.txt, and 'Save Target/File As...' to the Desktop.
>>> fileLocation = 'H:\Desktop\words.txt'
>>> word_file = open(fileLocation)
>>> print(word_file)
<open file 'words.txt', mode 'r' ... 
>>> word_file.readline()
'aa\ n'

(aa is a kind of lava.)
Files keep track of where reading takes place. Try reading a line again!

>>> word_file.readline()
'aah\ n'
>>> line = word_file.readline()
>>> line
'aahed\ n'
>>> line = line.strip()
>>> line
'aahed'

>>> for x in word_file:
    print(x)
(Don’t hit enter twice!)

Q: What will happen when I hit enter?

A:
9.2 Exercises

9.3 Searching

Q: How does a for loop work with a file? Example: for x in wordFile:

A:

>>> printWordsContaining('ape')
...

Implement it! Header:

Q:

def printWordsContaining(string):

Hint: use in!

A:
Talk about `.close()`.

```python
>>> printWordsUsingAll0f('aeiou')
...
```

Implement it! Warning: this one’s hard! Header:

```python
Q:
def printWordsUsingAll0f(characters):
(They probably won’t finish this! Move on after a few.)
```

Maybe it would help if we defined a different function first!

```python
>>> hasThemAll = usesAll0f('monkeyjeans', 'aeiou')
>>> print hasThemAll
False
>>> usesAll0f('monkeyjeans', 'mno')
True
>>> usesNone0f('monkeyjeans', 'zy')
False
>>> usesNone0f('monkeyjeans', 'zt')
True
```

Implement it! Header:

```python
Q:
def usesAll0f(string, characters):
Bonus Challenge: usesNone0f!
```
9.3 Searching

Q: Reimplement printWordsUsingAll to use usesAll. Bonus Challenge: printWordsUsingNoneOf

Q: What if I don’t trust words.txt or want to use a different list? How can I generalize printWordsUsingAll?

A:

〈 Ask students to download: https://dl.dropbox.com/u/43416022/150/woerter.txt. 〉

```python
>>> printWordsUsingAll('abcdefg', 'H:\Desktop\woerter.txt')
...
```

Generalize that to match! Header:

Q: printWordsUsingAll(characters, fileLocation):

A:
Q: What if I still use words.txt as a default?

A: Okay, let’s do this the other way around. Let’s write the function to test whether a word matches some criteria, then write a search to get all the matching words.

```python
>>> leftHandWord('monkey')
False
>>> leftHandWord('trees')
True
```

Q: When does this function return True?

A:
9.3 Searching

Implement it! Header:

Q: 

```
def leftHandWord(word):
```

Bonus challenge: Implement `rightHandWord`.

```>>> printLeftHandWords()
...
```

Implement it! Header:

Q: 

```
def printLeftHandWords():
```

Hint: use `leftHandWord` Bonus Challenge: `printRightHandWords()`

These all use the same searching “pattern”: `for` loop traverses all the words in the file and a boolean function tests to see if the word matches.

```>>> isAbecedarian('monkey')
False
>>> isAbecedarian('art')
True
```
Q: When does this function return True?

A:

Implement it! Header:

```python
def isAbecedarian(word):
```

Q: Progressive hints:
- use indices
- Can use iteration (while loop) or recursion! Whoa!
- 3 solutions in the text.

Those three solutions are on page 86\(^\text{16}\).

```python
>>> printAbecedarianWords()
...
```

Implement it! Header:

```python
def printAbecedarianWords():
```

Bonus challenge: `printReverseAbecedarianWords()`

\(^{16}\text{http://greenteapress.com/thinkpython2/thinkpython2.pdf#page=108}\)
Implement it! Header:

```python
def printPalindromes():
    # Hint: already did isPalindrome()
```

```python
>>> isReversibleWord("radar")
True
>>> isReversibleWord("evil")
True
```
Implement it! Header:

```
def isReversibleWord(word):
```

```
>>> printReversibleWords()
...
```
Q: Implement it! Header:

```python
def printReversibleWords():
```

Q: Why does this take so long?

A: If there are \( n \) words, other searches take linear time (function in terms of \( n \)) but `printReversibleWords` takes quadratic time (function in terms of \( n^2 \)).

There is a way to speed this up!

```python
>>> speedyPrintReversibleWords()
...
```

You’ll learn how to do that sort of stuff in Comp 250.

10 Lists

10.1 Lists are Sequences

Def: list A list is a data type that is a sequence of any values. Unlike a string, a list can contain more than characters.
Def: *elements* The values in a list are known as the *elements.*

```python
>>> prime_list = [2, 3, 5, 7, 11, 13, 17]
>>> print(prime_list)
[2, 3, 5, 7, 11, 13, 17]
>>> palindrome_list = ['a', 'I', 'radar', 'racecar']
>>> print(palindrome_list)
... >>> type(palindrome_list)
<type 'list'>
```

Elements don’t even need to be the same type!

```python
>>> junx = [3.45, 'spam', 405, ['monkey', 5]]
```

Nested: a list within a list!

```python
>>> empty = []
```

You can index lists just like strings.

```python
>>> print(junx[1])
spam
>>> junx[1]
'spam'
```

10.2 Lists are Mutable

Unlike strings, lists are mutable!
10.2 Lists are Mutable

```python
>>> junx[1] = 'spamspamspam'
>>> print(junx)
[3.45, 'spamspamspam', 405, ['monkey', 5]]

Just like strings:

- any integer expression can be used as index
- IndexError from non-existent elements
- in will test inclusion (but not sublists)

```python
>>> 'spamspamspam' in junx
True
>>> 'banana' in junx
False
>>> ['monkey', 5] in junx
True
>>> [3.45, 'spamspamspam'] in junx
False
>>> 'monkey' in junx
False

```python
>>> monkeys = ['tamarin', 'green monkey', 'macaque', 'marmoset', 'capuchin']
>>> swap_ends(monkeys)
>>> print(monkeys)
['capuchin', 'green monkey', 'macaque', 'marmoset', 'tamarin']
```
Q: Code up `swap_ends(t)`. Note: this function should be void. Bonus challenge: look up multiple assignment in Python and write the body in one line.

A:
>>> songs = ['subdivisions', 'tom sawyer', 'the trees', 'xanadu']
>>> index = 0
>>> while index < len(songs):
    print(songs[index])
    index += 1
...
subdivisions
...

>>> for song in songs:
    print(song)
...
subdivisions
...

>>> for song in songs:
    print(len(song))
...
12
...

Let’s do an example modifying the list in the loop!

>>> import math
>>> numbers = [.5, -1, 8, math.pi, 1337]
>>> index = 0
>>> while index < len(numbers):
    numbers[index] = 2 * numbers[index]
    index += 1
...

>>> print(numbers)
[1.0, -2, 16, 6.28..., 2674]
Q: Can we use a `for` loop here?

A:

```python
>>> for number in numbers:
    number = 3 * number
...
>>> print(numbers)
[1.0, -2, 16, 6.28..., 2674]
```

Didn’t change from last time! However...

```python
>>> for i in range(len(numbers)):
    numbers[i] = 3 * numbers[i]
...
>>> print(numbers)
```

Wow, that worked! Wha-? Why? How?

TODO: this no longer works in Python 3.
What to say instead?
```python
>>> range(len(numbers))
[0, 1, 2, 3, 4]
```

Q: What does the loop look like that would put the list back to normal? Write it!

A:
>>> stuff = [math.pi, 42, 'Neo', True, 0.01, [5, 10], math.sqrt]
>>> to_strings(stuff)
>>> print(stuff)
['3.14159265358979', '42', 'Neo', 'True', '0.01', '[5, 10]', '<built-in function sqrt>']
>>> pokemon = ['bulbasaur', 'squirtle', 'charmander']
>>> to_mankeys(pokemon)
>>> print(pokemon)
['mankey', 'mankey', 'mankey']
>>> junk = [['blah', 50], 'blah', ['blah', [5]]]
>>> to_mankeys(junk)
>>> print(junk)
[['mankey', 'mankey'], 'mankey', ['mankey', ['mankey', ['mankey']]]]

Q: Write to_strings(t). Bonus challenge: to_mankeys. Note that this goes as deep as necessary! Hint: recursion on list elements.

10.4 List Operations

There are other similarities to strings!
>>> x = [1]
>>> x = x + [2, 3]
>>> print(x)
[1, 2, 3]
>>> x = x * 3
>>> print(x)
[1, 2, 3, 1, 2, 3, 1, 2, 3]

>>> get_ones(5)
[1, 1, 1, 1, 1]
>>> three_ones = get_ones(3)
>>> print(three_ones)
[1, 1, 1]
>>> evens = get_evens(6)
>>> print(evens)
[0, 2, -2, 4, -4, 6]
>>> get_evens(0)
[]


A:
>>> numbers = [4, 5, 6, 7]
>>> backwards = get_reverse_of(numbers)
>>> print('backwards:', backwards)
backwards: [7, 6, 5, 4]
>>> print('numbers:', numbers)
numbers: [4, 5, 6, 7]
>>> reverse_elements(numbers)
>>> print('numbers:', numbers)
numbers: [7, 6, 5, 4]

Q: Code get_reverse_of(t). Note: this doesn’t modify the parameter. Hint: you need to use the most important list, the empty list! Bonus challenge: reverse_elements.

A: 

10.5 List Slices
10.5 List Slices

>>> x = [1, 2, 3, 1, 2, 3, 1, 2, 3]
>>> y = x[2:7]
>>> print(y)
[3, 1, 2, 3, 1]

Remember, lists are mutable. So we can do this...

>>> y[1:4] = [2.5, 2, 1.5]
>>> print(y)
[3, 2.5, 2, 1.5, 1]

>>> reverse_middle(y)
>>> print(y)
[3, 1.5, 2, 2.5, 1]

>>> monotrenes = ['platypus', 'echidna']
>>> reverse_middle(monotrenes)
>>> print(monotrenes)
['platypus', 'echidna']

>>> shift_elements(y)
>>> print(y)
[2.5, 2, 1.5, 1, 3]

>>> shift_elements(y)
>>> print(y)
[2, 1.5, 1, 3, 2.5]

A:

We can include a third part to slices!

```python
>>> primates = ['tamarin', 'lemur', 'orangutan', 'chimpanzee', 'gorilla']
>>> primates[::2]
['tamarin', 'orangutan', 'gorilla']
>>> primates[::-2]
['gorilla', 'orangutan', 'tamarin']
```

Q: Let’s go back to `reverse_elements` and try writing this using *in one line* using slices. (If you’ve already done it, save that version and try to add this version.)

A:
10.6    List Methods

lists also have methods!

```python
>>> x.append(.5)
>>> print(x)
[3, 2.5, 2, 1.5, 1, .5]
>>> x2 = [0, 3.5]
>>> x.extend(x2)
>>> print(x)
[3, 2.5, 2, 1.5, 1, .5, 0, 3.5]
>>> x.sort()
>>> print(x)
[0, .5, 1, 1.5, 2, 2.5, 3, 3.5]
```

Q: What is different about these methods as compared to string methods?

A: 

Q: Are they fruitful?

A: 
```python
>>> numbers = [1, 9, 5, 5, 3, 7, 8, 2]
>>> reverse_sort(numbers)
>>> print(numbers)
[9, 8, 7, 5, 5, 3, 1]
>>> sorted = get_sorted_copy(numbers)
>>> print('sorted:', sorted)
sorted: [1, 3, 5, 5, 7, 8, 9]
>>> print('numbers:', numbers)
numbers: [9, 8, 7, 5, 5, 3, 1]
```

Q: Code `reverse_sort(t)`.

Bonus challenge: get_sorted_version.

A:
10.7 Map, Filter, and Reduce

Often we want to sum a list.
10.7 Map, Filter, and Reduce

>>> total = list_sum([6, 7, 8])
>>> print(total)
21
>>> list_sum(x)
14
>>> all_even([6, 7, 8])
False
>>> integers = [12, 24, 36, 60, 4, 2]
>>> all_even(integers)
True

Implement it! Header:

**Q:**

```python
def list_sum(numbers):
    # Hint: use an accumulator variable, starting at 0. Bonus challenge: all_even.
```

**A:**

**Def:** *reduce operation* This sort of thing is called a reduce operation. A *reduce operation* takes a list and returns a single value.

Page 225 © 2020 Kyle Burke ☘️
```python
>>> more_numbers = [1, 5, 88, -4, 9, -999, 1]
>>> greatest = list_max(more_numbers)
>>> print(greatest)
88
>>> list_max(x)
3.5
>>> greatest_absolute =
list_max_absolute(more_numbers)
>>> print(greatest_absolute)
-999
```

**Q:** Are these both reduces?

**A:**
Implement it! Header:

Q:

```python
def list_max(numbers):
```

Bonus Challenge: implement `list_max_absolute`.

A:

```python
>>> exclamations = ['Bonus!', 'BOOyeah!', 'suhWEET!', 'WOOT!']
>>> little = all_lower_case(exclamations)
>>> print(little)
['bonus!', 'booyeah!', 'suhweet!', 'w00t!']
>>> print(exclamations)
['Bonus!', 'BOOyeah!', 'suhWEET!', 'WOOT!']
>>> pokemon = ['bulbasaur', 'ivysaur', 'venusaur', 'squirtle']
>>> abbreviate_and_sort(pokemon)
['bulb', 'ivys', 'squi', 'venu']```
Q: Is this a reduce operation?

A: 


A: 

This sort of operation is a map.

Def: map operation A map operation does something to each element in the list. This does not need to be fruitful!

```
>>> odds = [1, 3, 5, 7, 9]
>>> add_five_to_all(odds)
>>> print(odds)
[6, 8, 10, 12, 14]
>>> round_up_to_squares(odds)
>>> print(odds)
[9, 9, 16, 16, 16]
```
Q: Implement it! Header: `add_five_to_all(numbers)` Hint: this function is void!

A:

That one modifies the list instead of being fruitful. Hmm...

```python
>>> integers = [0, -5, -3, 22, 1337, 42]
>>> odds = only_odds(integers)
>>> print(odds)
[-5, -3, 1337]
>>> print(integers)
[0, -5, -3, 22, 1337, 42]
>>> split_evens_and_odds([1, 2, 3, 4, 5])
[[2, 4], [1, 3, 5]]
```

Q: Is this a map operation?

A:

**Def:** *filter operation* A filter operation "filters out" some elements of the list.
Implement it! Header: only_odds(integers) Hint: creates a new list. Bonus challenge: split_evens_and_odds. Double bonus challenge: write split_evens_and_odds in only 4 lines.

```python
>>> caps = only_caps(exclamations)
>>> print(caps)
['WOOT!']
>>> only_caps(['I', 'LOVE', 'monkeys'])
['I', 'LOVE']
>>> caps_from_each(exclamations)
['B!', 'BOO!', 'WEET!', 'WOOT!']
```

Q: Is this also a filter?

A: 
10.8 Deleting Elements

Let’s remove the negative values from our list.

```python
>>> integers = [0, -5, -3, 22, 1337, 42]
>>> x = integers.pop(1)
>>> print(integers)
[0, -3, 22, 1337, 42]
>>> print(x)
-5
>>> x = integers.pop(1)
>>> print(integers)
[0, 22, 1337, 42]
>>> print(x)
-3
```
Q: What is pop?

A: We can also use `del` to remove elements.

```python
>>> del integers[0]
>>> print(integers)
[22, 1337, 42]
>>> m = del integers[2]
Error!
>>> print(m)
NameError: name 'm' is not defined
>>> del integers[2]
>>> print(integers)
[22, 1337]
```

A `del` statement is a special kind of statement. It does not return a value. We can also use it on a slice!

```python
>>> letters = ['r', 'e', 's', 'p', 'e', 'c', 't']
>>> del letters[3:6]
>>> print(letters)
['r', 'e', 's', 't']
```

If we want to remove an element but don’t know the index, we can use the `remove` method!
10.8 Deleting Elements

```python
>>> letters = ['r', 'e', 's', 'p', 'e', 'c', 't']
>>> letters.remove('s')
>>> print(letters)
['r', 'e', 'p', 'e', 'c', 't']
>>> letters.remove('e')
>>> print(letters)
['r', 'p', 'e', 'c', 't']
```

With these tools, we can write void filters!

```python
>>> integers = [0, -5, -3, 22, 1337, 42]
>>> remove_evens(integers)
>>> print(integers)
[0, -5, -3, 1337]
>>> x = [2, 4, 6, 8, 10, 12, 14]
>>> remove_evens(x)
>>> x
[]
>>> integers = [0, -5, -3, 22, 1337, 42]
>>> shrinkify(integers)
>>> print(integers)
[-2.5, -1.5, 11, 668.5, 21]
>>> shrinkify(integers)
>>> print(integers)
[-1.25, 5.5, 334.25, 10.5]
```
Q: Code `remove_evens(integers)`. Hint: a for loop won’t work, you need to use a while! Bonus challenge: `shrinkify`.

A:

```python
>>> things = ['monkey', 32.64, None, 'cheese']
>>> delete_all(things)
>>> things
[]
>>> things.append(27.4)
>>> things
[27.4]
>>> delete_all(things)
>>> things
[]
>>> things = [2, 4, 6, 8, 10, 12]
>>> delete_elements(things, [1, 4])
>>> things
[2, 6, 8, 12]
>>>```
Q: What does delete_all do?

A: Deletes all elements in the list.

Q: Implement delete_all!
   Bonus challenge: delete_elements.

A:

10.9 Lists and Strings

There are some cute things we can do with lists and strings!

```python
>>> word = "subdivisions"
>>> letters = list(word)
>>> print(letters)
['s', 'u', ..., 's']
>>> string = "a farewell to kings"
>>> words = string.split()
>>> print(words)
['a', 'farewell', 'to', 'kings']
```

We can use a different delimiter!
>>> hyphenated = "crazy-angry-monkeys"
>>> hyphenated.split()
['crazy-angry-monkeys']
>>> hyphenated.split('-')
['crazy', 'angry', 'monkeys']

And we can rejoin strings!

>>> delimiter = ",
>>> delimiter.join(words)
'a farewell to kings'

Let’s write some functions with these methods!

>>> phrase = "my mom said that I need to eat seventeen apples"
>>> sort_words(phrase)
'I apples eat mom my need said seventeen that to'
>>> sorted = sort_words("electrode diglett nidoran mankey venusaur rattata fearow pidgey")
>>> print(sorted)
'diglett electrode fearow mankey nidoran pidgey venusaur'
>>> sort_words_by_length(phrase)
'I my to mom eat said that need apples seventeen'
Q: Code `sort_words(string)`. Bonus challenge: `sort_words_by_length`. (Really hard! I used two nested while loops!)

10.10 Objects and Values

```python
>>> a = 'monkey'
>>> b = 'monkey'
>>> a is b
True
```

Q: What might `is` mean?

A:

( Draw pointer picture! )
This doesn’t work with all objects.

```python
>>> c = [1, 4, 9]
>>> d = [1, 4, 9]
>>> c is d
False
```

These `equivalent`, not `identical`!

( Draw pointer picture! )
Q: What happens if I change a value in one of them?

A:

```python
>>> c[1] = 2
>>> print(c)
[1, 2, 9]
>>> print(d)
[1, 4, 9]
```

10.11 Aliasing

We can make them identical.

```python
>>> e = [1, 4, 9]
>>> f = e
>>> e is f
True
```

Q: Now what happens if I change e?

A:
>>> e[1] = 16
>>> print(e)
[1, 16, 9]
>>> print(f)
[1, 16, 9]

This can be a problem if you’re not expecting it.

>>> a = [1, 4, 9]
>>> b = a
>>> a = [1, 2, 3]

Q: What is the value of \( b \) now?

A: TODO: can I come up with any good functions for this?

10.12 List Arguments

Let’s define some functions that remove the zeroeth element from a list!
>>> def delete_head(valueList):
    del t[0]
...
>>> a = [1, 4, 9]
>>> delete_head(a)

Q: What is the value of a now?

A: 

( Draw the pointer picture! )

Q: Is delete_head fruitful?

A: 

>>> a = [1, 4, 9]
>>> x = delete_head(a)
>>> x
None

Another!
```python
>>> def other_delete_head(values):
    values = values[1:]
    return values
...
>>> a = [1, 4, 9]
>>> x = other_delete_head(a)
```

Q: What are the values of \(a\) and \(x\)?

A:

`delete_head` modifies the original list, `other_delete_head` does not.

( Draw the pointer picture! )

Another one!

```python
>>> def another_delete_head(values):
    values = values[1:]
...
>>> a = [1, 4, 9]
>>> x = another_delete_head(a)
```

Q: What are the values of \(a\) and \(x\)?

A:
Q: What does another_delete_head do?

A:

TODO: I can’t think of any good functions for this part right now. Let students work on their projects? O:-)

11  Dictionaries

Skipped this section in class.

12  Tuples

Skipped this section in class.

13  Case Study: Data Structure Selection

Skipped this section in class.

14  Files

Skipped this section in class.
15 Classes and Objects

15.1 User-Defined Types

We have seen a few different Data Structures: strings and list. These are both objects.

Let’s create our own type! A Pokemon type!

**Def:** class A class is a (user-defined) type.

(In Script:)

```python
class Pokemon(object):
    '''Represents a Pokemon.''
```

(Interactive Mode)

```python
>>> print(Pokemon)
<class '__main__.Point'>
>>> pyro = Pokemon()
>>> pyro (not print(pyro))
<_main__.Pokemon instance ...>
>>> schiggy = Pokemon()
>>> schiggy
<_main__.Pokemon instance ...>
```

**Q:** Why does Python print out all that nonsense?

**A:**
pyro is now an instance of the Pokemon class.

**Def:** An instance of a type is a value that has that type. 5 is an instance of int, 'hi' is an instance of str.

**Def:** An object is an instance of a class.

## 15.2 Attributes

We can assign blank attributes, which are named elements of an object.

```python
>>> pyro.name = 'Flareon'
>>> pyro.number = 136
>>> pyro.types = ['Fire']
>>> pyro.hit_points = 71
>>> pyro.max_hp = 77
>>> schiggy.name = 'Squirtle'
>>> schiggy.number = 7
>>> schiggy.types = ['Water']
>>> schiggy.hit_points = 56
>>> schiggy.max_hp = 56

We can represent this state with an object diagram.  
( Draw figure here! )
```

```python
>>> print(pyro.hit_points)
71
>>> pyro.hit_points < pyro.max_hp
True
```

( Let’s define some functions on our Pokemon! )
>>> has_full_hp(pyro)
False
>>> has_full_hp(schiggy)
True
>>> is_fainted(pyro)
False
>>> pyro.hit_points = 0
>>> is_fainted(pyro)
True

Q: Challenge: def has_full_hp(pokemon): Bonus Challenge: is_fainted

A:

It would be really helpful to have a function to print a Pokemon...
>>> print_pokemon(pyro)
Pokemon: Flareon (136) HP: 0/77
>>> print_pokemon(schiggy)
Pokemon: Squirtle (4) HP: 56/56
>>> get_types_string(pyro)
'Fire'
>>> get_types_string(schiggy)
'Water'
>>> gary = Pokemon()
>>> gary.name = 'Gyarados'
>>> gary.number = 130
>>> gary.types = ['Water', 'Flying']
>>> gary.hit_points = 83
>>> gary.max_hp = 83
>>> get_types_string(gary)
'Water/Flying'
>>>
Q: Challenge: `print_pokemon(pokemon)`. Bonus Challenge: `get_types_string`.

A:

15.3 Rectangles

Pokemon instead!

15.4 Instances as Return Values

TODO: I couldn’t think of any functions for here.

15.5 Objects are Mutable
15.5 Objects are Mutable

```python
>>> print_pokemon(pyro)
Pokemon: Flareon (136) HP: 0/77
>>> heal_up(pyro)
>>> print_pokemon(pyro)
Pokemon: Flareon (136) HP: 77/77
>>> pyro.hit_points = 35
>>> print_pokemon(pyro)
Pokemon: Flareon (136) HP: 35/77
>>> spray_potion(pyro)
>>> print_pokemon(pyro)
Pokemon: Flareon (136) HP: 55/77
>>> spray_potion(pyro)
>>> print_pokemon(pyro)
Pokemon: Flareon (136) HP: 75/77
>>> spray_potion(pyro)
>>> print_pokemon(pyro)
Pokemon: Flareon (136) HP: 77/77
```

Q: Challenge: heal_up(pokemon). Bonus challenge: spray_potion

A:
16 Classes and Functions

Note: This is all sectioned by my stuff since I’m not covering the Time stuff here. TODO: go through this and make it line up better with the book topics. :)

It’s kind of annoying to need so many lines to create a Pokemon object. Let’s use a new function to create them!

```python
>>> vandal = create.pokemon('Jigglypuff',
number = 39, types = ['Normal', 'Fairy'], hp = 44)
>>> print.pokemon(vandal)
Pokemon: Jigglypuff (39) HP: 44/44
>>> schiggy = create.pokemon('Squirtle', 7,
['Water'], 56)
```
Q: Implement `create_pokemon`!

A:

16.1 Pure Functions

16.2 Modifiers

Def: **pure function** A *pure function* returns a value, but doesn’t modify the parameters.

Def: **modifier** A *modifier* modifies one of the parameters, but doesn’t return a value.

<table>
<thead>
<tr>
<th></th>
<th>Modifies Parameters?</th>
<th>Modifies Parameters?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fruitful?</td>
<td>Fruitful</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Pure Function</td>
<td></td>
</tr>
<tr>
<td>Fruitful?</td>
<td>Void</td>
<td>Modifier</td>
</tr>
<tr>
<td></td>
<td>Neither (Prints?)</td>
<td></td>
</tr>
</tbody>
</table>
Q: Which of the above is `print_pokemon`?

A:

Q: Which of the above is `spray_potion`?

A:
>>> seventh = get_first(schiggy, pyro)
>>> print_pokemon(seventh)
Pokemon: Squirtle (7) HP: 56/56
>>> earlier = get_first(pyro, gary)
>>> print_pokemon(earlier)
Pokemon: Gyarados (130) HP: 83/83
>>> schiggy.hit_points = 0
>>> print_pokemon(schiggy)
Pokemon: Squirtle (7) HP: 0/56
>>> revive(schiggy)
>>> print_pokemon(schiggy)
Pokemon: Squirtle (7) HP: 28/56
>>> gary.hit_points = 0
>>> print_pokemon(gary)
Pokemon: Gyarados (130) HP: 41/83
>>> revive(gary)
This Gyarados is not fainted.


A:
>>> ordered = order_pokemon(gary, pyro, schiggy)
>>> print(ordered)
[<Pokemon...>, <Pokemon...>, <Pokemon...>]
>>> for pokemon in ordered:
... print_pokemon(pokemon)
...
Pokemon: Squirtle (7) HP: 28/56
Pokemon: Gyarados (130) HP: 41/83
Pokemon: Flareon (134) HP: 77/77
>>> pokemon_list = [vandal, pyro, schiggy, gary]
>>> sort_pokemon(pokemon_list)
>>> for pokemon in pokemon_list:
... print_pokemon(pokemon)
...
Pokemon: Squirtle (7) HP: 28/56
Pokemon: Jigglypuff (39) HP: 44/44
Pokemon: Gyarados (130) HP: 41/83
Pokemon: Flareon (134) HP: 77/77

Q: Code order_pokemon. Hard Bonus Challenge: sort_pokemon. (Hint: You probably need to have written the selection_sort project function first to get this one.)

A:
>>> pyro.hit_points = 0
>>> vandal.hit_points = 0
>>> fainted = get_fainted(pokemon_list)
>>> for pokemon in fainted:
...     print_pokemon(pokemon)
...
Pokemon: Jigglypuff (39) HP: 0/44
Pokemon: Flareon (134) HP: 0/77
>>> heal_up(vandal)
>>> injured = get_injured_but_lucid(pokemon_list)
>>> for pokemon in injured:
...     print_pokemon(pokemon)
...
Pokemon: Squirtle (7) HP: 28/56
Pokemon: Gyarados (130) HP: 41/83

Q:

Code `get_fainted`. Bonus challenge: `get_injured_but_lucid`. Bonus bonus challenge: come up with a better name for that last one for me. :) Bonus bonus bonus challenge: finish `sort_pokemon`. :-P

A:
16.3 Prototyping versus Planning

17 Classes and Objects

Q: Why are we bothering to do all this with objects? Why not just use lists instead? Why don’t we just use a list with three elements to represent a Date? (Don’t let them answer yet; keep going!)

>>> charchar = [’Charmander’, 1, [’Fire’], 23, 23]

17.1 Object Oriented Features

Q: What’s wrong with using a list?

A: • Names are clearer. Which of the elements above represents the month?
• We can specify what we want the attributes to be.
• Haven’t seen this yet, but methods!

The style of programming that uses objects is called: Object-Oriented Programming. Using this makes programs easier to read, understand, and change.
17.2 Printing Objects (Methods!)

Let’s harness more of this and write a method!

```
(In Script):
class Pokemon(object):
    '''Represents a Pokemon.
    attributes: name, number, types, hit_points, max_hp'''

    def print_pokemon(pokemon):
        '''Nicely prints a pokemon.'''
        output = 'Pokemon: ' + pokemon.name + ' (' + str(pokemon.number) + ') HP: ' + str(pokemon.hit_points) + '/' + str(pokemon.max_hp)
        print(output)
```
Q: What did I actually change?

A: Moved `print_pokemon`'s definition into the class.

Q: Now `print_pokemon` is a method! How do I invoke it?

A: 

\langle Break down the syntax of the two invocation options! \rangle

**Def:** *subject* The *subject* of a method is the object the method is invoked on.

The idea here is that the subject takes an active role in invoking the method. Instead of: “Hey function, print this Pokemon!” we’re saying: “Hey Pokemon, print yourself!”

Usually, the subject is named `self` in all methods. Let’s change our script!
(In Script):
class Pokemon(object):
    '''Represents a Pokemon.
    attributes: name, number, types, hit_points, max_hp'''

def print_pokemon(self):
    '''Nicely prints a pokemon.'''
    output = 'Pokemon: ' + self.name + ' (' + str(self.number) + ') HP: ' + str(self.hit_points) + '/' + str(self.max_hp)
    print(output)

Q: Would I ever need a guardian to be certain that self is a Pokemon?

A: 

Q: Is the method’s name very appropriate?

A: Not especially. If it’s already a Pokemon, you don’t need that word in the method name.
Q: What would be more appropriate?

A:

Let’s see how that looks.

```python
>>> schiggy = create_pokemon('Squirtle', 7, ['Water'], 56)
>>> schiggy.hit_points = 28
>>> schiggy.print()
Pokemon: Squirtle (7) HP: 28/56
>>> pyro = create_pokemon('Flareon', 134, ['Fire'], 77)
>>> pyro.print()
Pokemon: Flareon (134) HP: 77/77
>>> pyro.get_types_string()
'Fire'
```
Q: Rename `print_pokemon` from above into the `print` method here.
   Bonus Challenge: turn `get_types_string` into a method.

A:

17.3 Another Example (Increment)

Q: Can we translate our other functions into methods?

A: Absolutely!
```
>>> schiggy = create.pokemon('Squirtle', 7, ['Water'], 56)
>>> schiggy.hit_points = 28
>>> pyro = create.pokemon('Flareon', 134, ['Fire'], 77)
>>> schiggy.has_full_hp()
False
>>> pyro.has_full_hp()
True
>>> schiggy.is_fainted()
False
>>> schiggy.hit_points = 0
>>> schiggy.is_fainted()
True
```

**Q:** "Methodize" `has_full_hp`.  
Bonus: `is_fainted`.

**A:**

Let’s turn all of our other functions into methods!
>>> schiggy = create.pokemon('Squirtle', 7, ['Water'], 56)
>>> schiggy.hit_points = 28
>>> schiggy.heal_up()
>>> schiggy.print()
Pokemon: Squirtle (7) HP: 56/56
>>> schiggy.hit_points = 0
>>> schiggy.revive()
>>> schiggy.print()
Pokemon: Squirtle (7) HP: 28/56
>>> schiggy.spray_potion()
>>> schiggy.print()
Pokemon: Squirtle (7) HP: 48/56

Q: Methodize heal_up.
Bonus challenges: revive and spray_potion.

A:
17.4 A More Complicated Example (is_after)

Q: How could we "methodize" something like 
   get_first(poke0, poke1)?

A: It’s not really the same, since it has two sub-
   jects. Let’s do something a bit different instead.
>>> schiggy = createpokemon('Squirtle', 7, ['Water'], 56)
>>> pyro = createpokemon('Flareon', 134, ['Fire'], 77)
>>> gary = createpokemon('Gyarados', 130, ['Water', 'Flying'], 83)
>>> vandal = createpokemon('Jigglypuff', number = 39, types = ['Normal', 'Fairy'], hp = 44)
>>> schiggy.is_after(pyro)
False
>>> pyro.is_after(gary)
True
>>> pokemon_list = [schiggy, vandal, pyro]
>>> gary.heal_up()
>>> gary.more_hp_than_all(pokemon_list)
True
>>> pyro.more_hp_than_all([schiggy, vandal, gary])
False

Q: Methodize it! Header: def is_after(self, other)
Bonus Challenge: more_hp_than_all

A:
We can change the syntax for creating new objects!

17.5 The init Method

```python
>>> mankey = Pokemon()
>>> mankey.initialize("Mankey", 56, ['Fighting'], 51)
>>> mankey.print()
Pokemon: Mankey (56) HP: 51/51

>>> bulby = Pokemon()
>>> bulby.initialize()
>>> bulby.print()
Pokemon: Bulbasaur (1) HP: 1/1
```

This is a bit different than `create_pokemon`... but I’m getting somewhere, don’t worry!
Implement it! Header:

**Q:**

```python
def initialize(self, number = 1, name = 'Bulbasaur', types = ['Grass'], hp = 1):
```

```python
def initialize(self, number = 1, name = 'Bulbasaur', types = ['Grass'], max_hp = 1, hp = max_hp):
    '''Initializes a Pokemon object.''
    self.number = number
    self.name = name
    self.types = types
    self.max_hp = max_hp
    self.hit_points = hit_points
```

**A:**

Then I renamed mine to have this funny name:

```python
>>> bulby = Pokemon()
>>> bulby._init__(hp = 10)
>>> bulby.print()
Pokemon: Bulbasaur (1) HP: 10/10
``` 

Now it’s time for something crazy!

```python
>>> bulby = Pokemon(hp = 10)
>>> bulby.print()
Pokemon: Bulbasaur (1) HP: 10/10
```
Q: How did that happen?

A: The `__init__` method is automatically called when you create an object!

```python
>>> mankey = Pokemon("Mankey", 56, ['Fighting'], 51)
>>> mankey.print()
Pokemon: Mankey (56) HP: 51/51
```  

Try it out! Rename your method from `initialize` to `__init__`. (Yes, all four underscores are necessary.)

Q: What is weird about `__init__`?

A:
Q: So what actually happens here?

Python uses the `__init__` method (called a constructor you write to define the attributes. Two things happen after you create an object:

- First, the object is created, then
- The `__init__` method is called with whatever parameters were given to the creator.

A: How could we pretend that code looks?

```python
def Pokemon(number, name, types, hp):
    object = python-creates-object
    object.__init__(number, name, types, hp)
    return object
```
17.5 The _init_ Method

Q: Does this work for all new object types?

Yes!

def ObjectName(...same parameters as constructor...):
    object = python-creates-object
    object.__init__(...put the parameters here...)
    return object

A:

Let’s create another class!

```python
>>> mw_latitude = GeographicCoordinate('N', 44, 16, 13.8)
>>> mw_longitude = GeographicCoordinate('W', 71, 18, 11.7)
>>> print_coordinate(mw_latitude)
44°16’13.8"N
>>> print_coordinate(mw_longitude)
71°18’ 11.7"W
>>> x = GeographicCoordinate('S', 110, 11, 3.2)
Error!
>>> x = GeographicCoordinate('X', 1, 1, 1)
Error!
>>>```

Q: What do you think the names of the attributes should be?
A: I named mine direction, degrees, minutes, and seconds.

Q: Let’s write a print_coordinate function before we do anything else.
    Hint: for the degree symbol in Python 3, use: ‘\u00b0’.
    Bonus challenge, turn it into a print method.

A: def print_coordinate(coordinate):
    """Prints a GeographicCoordinate"
    print(str(coordinate.degrees) + '\u00b0' +
    str(coordinate.minutes) + '\''
    + str(coordinate.seconds) + ''
    + coordinate.direction)
Q: Implement `GeographicCoordinate.__init__`. 
Bonus challenge: do it with the guardians.

A:
**Def:** *special method* A Python method that uses the four underscores is known as a *special method*. We’ll see more soon! Special methods can be invoked without explicitly typing out the call.

**Q:** Are there more special methods we can use?

**A:** Absolutely!

### 17.6 The `__str__` Method

```python
guardian = Pokemon('Abra', 63, ['Psychic'], 22)
>>> guardian
Pokemon: Abra (63) HP: 22/22
>>> print(guardian)
Pokemon: Bulbasaur (1) HP: 1/1
```

**Q:** Wow! How did that happen?

**A:** Another special method: `__str__`!
Q: Write it!

A: 

Q: When is this called?

A: 

Page 273 © 2020 Kyle Burke
Q: Why is this method better than the `print_pokemon` function?

A:

Q: When creating a new class, which should be the first methods you define?

A:

Q: Why?

A:

I created some new classes with `__init__` and `__str__` methods.
>>> mw_latitude = GeographicCoordinate('N', 44, 16, 13.8)
>>> mw_longitude = GeographicCoordinate('W', 71, 18, 11.7)
>>> print(mw_latitude)
44°16’13.8"N
>>> print(mw_longitude)
71°18’11.7"W
>>> mw_latitude.is_latitude()
True
>>> mw_latitude.is_longitude()
False

Q: Challenge: Implement __str__. Bonus challenge: implement is_latitude and is_longitude.

A:
```
>>> mw_location = Location(mw_latitude, mw_longitude)
>>> print(mw_location)
(44°16’13.8"N, 71°18’11.7"W)
>>> mw_backwards = Location(mw_longitude, mw_latitude)
This is not a legitimate location!
Longitude and latitude are incorrect!
```
>>> washington = Mountain('Mount Washington', 1916.6, mw_location)
>>> print(washington)
Mount Washington (1916.6m tall @ (44°16’13.8"N 71°18’11.7"W))

>>> nearby = Mountain('Plymouth Mountain', 670, Location(GeographicCoordinate('N', 43, 42, 32.04), GeographicCoordinate('W', 71, 43, 24.96)))

>>> print(nearby)
Plymouth Mountain (670m tall @ (43°42’32.04"N 71°43’24.96"W))

>>> pemi = River('Pemigewasset River', 104.6, Location(GeographicCoordinate('N', 43, 26, 12), GeographicCoordinate('W', 71, 38, 55)))

>>> print(pemi)
The Pemigewasset River is 104.6km long. Its mouth is at (43°26’12"N, 71°38’55"W).

>>>
Q: Code the Mountain class, with __init__ and __str__ methods. Bonus challenge: do the same for River.

A:

```python
>>> washington.taller_than(nearby)
True
>>> nearby.taller_than(washington)
False
>>> washington.taller_than(washington)
False
```
Q: Implement `taller_than`. Bonus: do it in one line.

A:

```python
>>> perfect_spring_day = WeatherReport("Plymouth", 63, 49, "Partly Cloudy")
>>> print(perfect_spring_day)
Today in Plymouth, the weather is Partly Cloudy with a high of 63F and a low of 49F.
>>> weather = WeatherReport("Lake Buena Vista", 91, 73, "Mostly Sunny")
>>> print(weather)
Today in Lake Buena Vista, the weather is Mostly Sunny with a high of 91F and a low of 73F.
```

Or you could code it to do both Celsius and Fahrenheit, with Fahrenheit as the default:
weather = WeatherReport("Lake Buena Vista", 91, 73, "Mostly Sunny")
>>> print(weather)
Today in Lake Buena Vista, the weather is Mostly Sunny with a high of 91F/33C and a low of 73F/23C.
>>> rainy_munich_day = WeatherReport("Muenchen", 13, 18, "Scattered Showers", "Celsius")
>>> print(rainy_munich_day)
Today in Muenchen, the weather is Scattered Showers with a high of 64F/18C and a low of 55F/13C.
>>>
Q: Code `WeatherReport` (without celsius). Bonus challenge: do the celsius ↔ fahrenheit conversion. (Hint: I wrote a separate function to go back and forth between C and F.)

A:
18 Inheritance

To skip to new stuff not covered in the textbook, jump to Section 18.7.

18.1 Card Objects

Q: Let’s play cards! What do we need?

A:

Q: What are our attributes going to be?

A:

Q: Hard: What types will we use for our attributes?

A:

What? How does that work? We’re going to encode the different suits:

• 3 means Spades
• 2 means Hearts
18.1 Card Objects

- 1 means Diamonds
- 0 means Clubs

**Q:** How could we encode the card values? (Ace, King, \ldots, 2)

**A:**
>>> spade_five = Card(3, 5)
Write the class and the constructor!

Q:
Bonus Challenge:
>>> club_two = Card()
Write it with default parameters to Clubs and 2.

A:
>>> spade_five = Card(3, 5)
>>> print(spade_five)
5 of Spades

>>> club_two = Card()
>>> print(club_two)
2 of Clubs

>>> print(Card(2, 12))
Queen of Hearts

Write `__str__`. Bonus challenge: write it so the Jack, Queen, King, and Ace are printed nicely like this.

A:
18.2 Class Attributes

So far, things are a bit inelegant. Let’s do some refactoring to improve things!

```python
(Script)
class Card(object):
    '''Models a playing card. Attributes:
suit and rank.''
    suit_names = ['Clubs', 'Diamonds', 'Hearts', 'Spades']
    rank_names = [None, 'Ace', '2', '3', '4', '5', '6', '7', '8', '9', '10', 'Jack', 'Queen', 'King']

    We can access these in the following way:

    >>> print(Card.suit_names[2])
    Hearts
    >>> print(Card.rank_names[12], 'of', Card.suit_names[0])
    Queen of Clubs

    These variables inside a class but not inside any methods are known as class attributes. Unlike instance attributes, these are not associated with a specific instance of the class. They are instead used by the class “at large”.
```
Those big conditionals are kind of ugly. Refactor \texttt{\_str\_} to use these lists. (Hint: the result will be much shorter!) Bonus Challenge: do it using print formatting.

If I look at a line of code: \texttt{XXXX.YYYY}, how do I know whether \texttt{YYYY} is a class or instance attribute?

How should you be able to tell just by looking at the name of \texttt{XXXX}?

Draw this diagram showing the class and the class attributes:
18.3 Comparing Cards

Warning: I think this part of the book is wrong. In Python 3, the `cmp` method doesn’t work the same way as it does in Python 2.

There are another pair of special methods in Python (3):

- `__lt__`: ”less than”
- `__eq__`: ”equals”

If I implement them, then I can start using the boolean comparison operators. (<, ==, and others!)

Q: What should `__eq__(self, other)` return?

A:
Q: Implement `__eq__` for the `Card` class.

A:

Q: Implement `__lt__` for `Card`. Cards should first compare their rank, then break ties based on the suit.
   Bonus challenge: write it in one line. (Hint: one long boolean statement)
   Super Bonus challenge: Write it so that the Ace is the highest card in the set.

A:

Now let’s play with these methods.
```python
>>> six = Card(1, 6)
>>> queen = Card(2, 12)
>>> queen < six
False
>>> six == queen
False
>>> six < queen
True
>>> clubs_queen = Card(0, 12)
>>> clubs_queen < queen
True
>>> queen < clubs_queen
False
>>> queen > six
ERROR!
```

**Q:** Why did that last one error?

**A:**

There are a bunch more comparison methods to implement:

- `_gt__`: >
- `_ge__`: ≥
- `_le__`: ≤
- `_ne__`: ≠

Thankfully, there’s a good way around this one so
we don’t have to implement all these methods: we can use the `total_ordering` decorator:

```python
from functools import total_ordering

class Card(object):
    ...
```

Now we can do all the comparing:

```python
>>> six = Card(1, 6)
>>> queen = Card(2, 12)
>>> clubs_queen = Card(0, 12)
>>> queen >= clubs_queen
True
>>> six != queen
True
```

18.4 Decks

Now let’s make a new object, a deck of cards!
class Deck(object):
    '''Represents a deck of cards.
    attributes: cards'''
    def __init__(self):
        '''Creates a new Deck object with all 52 cards.'''
        self.cards = []
        for suit in range(4):
            for rank in range(1, 14):
                card = Card(suit, rank)
                self.cards.append(card)

Wow! We just wrote a nested loop to create an object! Cool!

18.5 Printing the Deck

Q: What method should we write next?

A:
Q: How do we want this to work?

A:

Q: Write it! Bonus Challenge: write it so that it numbers the cards, like this:

0: 2 of Clubs
1: 3 of Clubs
...
51: Ace of Spades

A:
18.6 Add, remove, shuffle, and sort

Q: What operation might we want to often do from a deck of cards?

A:

---

Q: Great! Write a `deal()` method that removes the next card and returns it. Here’s what should happen:

```python
>>> card = deck.deal()
>>> print(card)
King of Spades

>>> print(deck.deal())
Queen of Spades
```

Hint: There’s a list method that does this in one line.

A:

---

Q: Is `deal()` a pure function or a modifier?

A:
```python
>>> hand = []
>>> for i in range(5):
...     hand.append(deck.deal())
... 
>>> print(hand)
[<Card object ...>, ...blahblah...]
>>> for i in range(5):
...     print(hand[i])
... 
Jack of Spades
10 of Spades
9 of Spades
8 of Spades
7 of Spades
```

**Q:** Oooh! A flush! Am I super lucky?

**A:**

**Q:** What should I do with the deck before I start dealing?

**A:**
18.6 Add, remove, shuffle, and sort

(shuffle example)

```python
>>> numbers = [1, 2, 3, 4, 5, 6]
>>> import random
>>> random.shuffle(numbers)
>>> print(numbers)
[some random permutation...]
```

Q: Let’s add a `shuffle()` method to the `Deck` class that shuffles the cards. Add it!

A:

```python
>>> deck = Deck()
>>> deck.shuffle()
>>> hand = []
>>> for i in range(5):
...    hand.append(deck.deal())
...
>>> for i in range(5):
...    print(hand[i])
...
5 random cards
```
Q: How many times should we shuffle the deck?

A:

Q: It’s a bit annoying to write a for loop everytime we need to deal out a hand. What should we do instead?

A:

Q: Do it! deal_hand

A:
Q:  
Okay, what’s annoying about this?

A:  

Q:  
Luckily, there’s a nice way to get it to print. We could turn each hand into an object, then use that object’s `__str__` method to print the cards. A hand is actually like a small version of a type we’ve already created. Which one?

A:  

I’ve modified `deal_hand` to return a `Deck`.

```python
>>> deck = Deck()
>>> deck.shuffle()
>>> hand = deck.deal_hand()
>>> print(hand)
... 5 random cards...
```
Write `deal_hand` so that the above code works. Hint: I modified my `Deck.__init__` method by changing the first two lines:

```python
def __init__(self, cards = None):
    '''Constructor.'''
    self.cards = cards
    if self.cards == None:
```

**Q:**

**A:**
We might also want a way to put cards back into the deck:

```python
>>> deck = Deck()
>>> len(deck.cards)
52
>>> deck.shuffle()
>>> card = hand.deal()
>>> len(deck.cards)
51
>>> deck.add_card(card)
>>> len(deck.cards)
52
Write `add_card`!
Bonus Challenge: write `Deck.size()`
```

Let's take a slight detour from things in the book...

I created a new class:
```python
>>> fuji = Volcano('Mount Fuji', 3776.24, Location(GeographicCoordinate('N', 35, 21, 29), GeographicCoordinate('E', 138, 42, 52)))
>>> print(fuji)
Mount Fuji (3776.24m tall @ (35°21’ 29"N, 138°43’52"E))
>>> fuji.taller_than(washington)
True
>>> fuji.is_active()
True
>>>
```

**Q:** Do we have to copy/paste a lot of code from Mountain?

**A:** No! We can use inheritance!
class Volcano(Mountain):
    ''' Models a volcano.
    attributes: active'''

    def __init__(self, name, height_in_m, location, active=False):
        '''Class constructor.''
        self.name = name
        self.height = height_in_m # in meters
        self.location = location
        self.active = active

Q: Try that out. Without doing anything else, which Volcano methods work? Which don’t?

A: __str__ and taller_than work, but is_active does not.

Q: Why is that?

A: Volcano inherits all of the attributes and methods from Mountain!
Q: Implement `is_active`

A:

Q: Is fuji a Mountain? Is washington a Volcano? How can we be sure in Python?

A:

```python
>>> isinstance(fuji, Mountain)
True
>>> isinstance(washington, Volcano)
False
```
```python
>>> fuji.add_eruption(1708)
>>> fuji.add_eruption(1864)
>>> fuji.last_eruption()
1707
>>> kilauea = Volcano('Kilauea', 1247,
                   Location(GeographicCoordinate('N', 19, 25, 16),
                   GeographicCoordinate('W', 155, 17, 12))):
>>> kilauea.add_eruption(1968)
>>> kilauea.add_eruption(1974)
>>> kilauea.add_eruption(2018)
>>> kilauea.last_eruption()
2018
>>> fuji.erupted_more_recently_than(kilauea)
False
```

**Q:** What do I need to modify before writing the methods.

**A:**
Q: Modify \_init\_, then implement add\_eruption and last\_eruption.
Bonus challenge: erupted\_more\_recently\_than.

A: 

Q: Inheritance is useful for removing repeated code. Is there any other code that is repeated between Volcano and Mountain?

A: Yes! Inside the constructors!

Q: Is there a way to remove that repetition?

A: Yes!
```python
class Volcano(Mountain):
    '''Models a volcano.
    attributes: active, eruptions'''

    def __init__(self, name, height_in_m, latitude, longitude, active=False):
        '''Class constructor.''
        super().__init__(name, height_in_m, location)
        self.active = active
        self.eruptions = []
```

**Q:** What does `super()` do?

**A:** It grabs the super class. Then we can explicitly call those methods!

**Q:** Can we use `super()` to make a better `__str__` for `Volcano`?

**A:** Yes!
(Note, this won’t work on mine without breaking it for the future)
>>> mountains = [fuji, washington, nearby, kilauea]
>>> for mountain in mountains:
...    print(mountain)
...
Mount Fuji (3776.24m tall @ (35°21’ 29”N, 138°43’52”E)) is an active volcano
Mount Washington (1916.6m tall @(44°16’13.8”N 71°18’ 11.7”W))
Plymouth Mountain (670m tall @(43°42’ 32.04”N 71°43’24.96”W))
Kilauea (1247m tall @(19°25’ 16”N, 155°17’ 12”)) is an active volcano

Q: How does Python know which class’s version of `__str__` to execute?

A: Python checks the objects type when it’s running, and sees if there’s a method of that name in that class. If not, it goes up to the super class and checks that, etc. This is called polymorphism.
Q: How far up does this checking go?

Until:

A:
- It finds a method with the correct name, or
- It goes all the way up to object and doesn’t find anything!

Q: How high does this chain go?

A: There’s no limit!

Q: How could we add child classes of Volcano so that there’s no active field?

A: (The dormancy of some of these volcanoes in my examples may become out of date.)
```python
>>> nyamuragira = ActiveVolcano("Nyamuragira", 3058, Location(GeographicCoordinate('S', 1, 24, 29), GeographicCoordinate('E', 29, 12, 00)))
>>> print(nyamuragira)
Nyamuragira (3058m tall @ (1°24’29"S, 29°12’0"E)) is an active volcano
>>> kea = DormantVolcano("Meana Kea", 4205, Location(GeographicCoordinate('N', 19, 49, 35), GeographicCoordinate('W', 155, 28, 28)))
>>> print(kea)
Mauna Kea (4205m tall @ (19°49’35"N, 155°28’28"W)) is a dormant volcano
```
Q: Implement both of them! Then remove `active` as a field from the Volcano class.

A:

Q: Now that we’ve remove the `active` field, which method should we remove from the `Volcano` class?

A: `is_active`

Q: Should we have `is_active` be a method in the subclasses?

A: Sure! And now they’re very easy to write!
Q: Implement them both!

A:

18.7.1 Polymorphism

Polymorphism is also covered a bit in the book in section 17.9.

Let’s practice using the methods we’ve written in some functions that take lists of Volcanoes. We won’t know whether the volcanoes are Active or Dormant ahead of time, so the method calls will use polymorphism.
>>> loa = ActiveVolcano("Mauna Loa", 4169,
                   Location(GeographicCoordinate(‘N’, 19, 28,
                                             46.3), GeographicCoordinate(‘W’, 155, 36,
                                             9.6)))
>>> kea = DormantVolcano("Mauna Kea",
                   4207.3, Location(GeographicCoordinate(‘N’,
                                              19, 49, 14), GeographicCoordinate(‘W’, 155,
                                              28, 5)))
>>> cerfs = DormantVolcano("Trou aux Cerfs",
                     605, Location(GeographicCoordinate(‘S’, 20, 18, 54),
                                   GeographicCoordinate(‘E’, 57, 30, 18.0)))
>>> erebus = ActiveVolcano('Mount Erebus',
                   3895, Location(GeographicCoordinate(‘S’, 77,
                                              31, 48), GeographicCoordinate(‘E’, 167, 10,
                                              12))
>>> volcanoes = [loa, kea, cerfs, erebus]
>>> active = get_active(volcanoes)
>>> for volcano in active:
    print(volcano)
...  
Mauna Loa (4169m tall @ (19°19’49"N,
                 155°28’5"W)) is an active volcano
Mount Erebus (3895m tall @ (77°31’48"S,
               167°10’12"E)) is an active volcano
>>> separated = separate_volcanoes(volcanoes)
>>> print(separated[0])
[<ActiveVolcano ...>, <ActiveVolcano ...>]
>>> print(separated[1])
[<DormantVolcano ...>, <DormantVolcano ...>]

Q: In `get_active`, do I need to use `isinstance` to test to see which type each volcano is?

A: Nope!

Q: Why not?

A: We can use the `is_active` method we already wrote.

Q: Write `get_active`.

Bonus challenge: write `separate_volcanoes`, which returns a list of two lists. The first is active volcanoes, the second is the dormant volcanoes.

A:
18.7 Inheritance

```python
>>> bulleted_volcanoes =
to_bulleted_string(volcanoes)
>>> print(bulleted_volcanoes)
* Mauna Loa (4169m tall @ (19°19’49"N, 155°28’5"W)) is an active volcano
* Mauna Kea (4205m tall @ (19°49’35"N, 155°28’28"W)) is a dormant volcano
* Trou aux Cerfs (605m tall @ (20°18’54"S, 57°30’18"E)) is a dormant volcano
* Mount Erebus (3895m tall @ (77°31’48"S, 167°10’12"E)) is an active volcano

>>> big = highest_active(volcanoes)
>>> print(big)
Mauna Loa (4169m tall @ (19°19’49"N, 155°28’5"W)) is an active volcano
```

**Q:** Do I need to test whether each volcano is active or dormant inside of `to_bulleted_string`?

**A:** Nope! We can just call the `str` method.
Q: Why does the \texttt{str} method do different things?

Because it uses the type of the object. Even though the loop code doesn’t know whether each volcano is an \texttt{ActiveVolcano} or a \texttt{DormantVolcano}, we can still call the \texttt{str} method and it will choose the correct version \textit{polymorphically}, based on the actual type of the volcano. This is called \textit{dynamic method invocation}.

Q: Implement \texttt{to_bulleted_string}.
   Bonus challenge: \texttt{highest_active}.

A:

19 The Goodies

This section of the book covers lots of cool things that are specific to Python. If you’re interested in learning more, definitely check this out!

I don’t have any problems for this material, as our
next class moves on to Java.

20 After Class

This is a pre-requisite for many courses, one of which is Data Structures. I prefer to teach that course in Java. There are quite a few differences to Java, but they are both imperative programming languages\(^\text{17}\). To help make the transition from Python to Java, I recommend looking at these things:

- Python-to-Java tutorial I wrote at https://turing.plymouth.edu/~kgb1013/pythonToJavaTutorial/start.php.
- The zeroeth project in my Data Structures course: https://turing.plymouth.edu/~kgb1013/?course=2381&project=0\(^\text{18}\). It is designed to be a tutorial-level project, so most of what you do is spelled out directly.
- If you want to start all over from the beginning, you can use the Java version of our textbook, available at: https://greenteapress.com/wp/think-java/.

I hope you enjoyed this course as much as I did and that these notes have been useful for you!

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\(^{17}\)https://en.wikipedia.org/wiki/Imperative_programming

\(^{18}\)Sometimes this project is not available because my course is starting again soon, but I haven’t opened the project up ahead of time. If you email me, I’ll get it working again.