Readings for Unit 7

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1) Introduction

Earlier in the course, we introduced the capability of *function definition*, which gave us the power to create functions that we could then abstract and treat as though they had been "built in" to Python. In the same way that we could use the built-in capabilities of, for example, addition or subtraction, we could create new variations on these operations and use the them as though they had been defined as part of Python.

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Turns out we can do the same thing, not with procedures, but with data. Just like Python came with several built-in operations and functions that we could then build on using function definition, Python also comes with several built-in data types (many of which you have experience with by now): `int`, `float`, `str`, `list`, `dict`, and a few others. In this set of readings, we'll explore a means for creating custom types of objects.

Then we'll take some time to explain a grab-bag of other Python features.

2) Classes and Instances

Way back in the first set of readings, we introduced *objects* as the main "things" that Python programs work with, and we noted that each object has both a *type* and a *value*: an object's value determines the exact thing it represents, and its type determines the kinds of things that programs can do to it (defines the set of valid operations on that type of object).

We will occasionally use different terminology: we can refer to an object's type as its *class*, and we can say that the object itself is an *instance* of that class.

For example, `int` is a class, and some examples of instances of that class are: `478`, `1`, and `3`. Similarly, `str` is a class, and some examples of instances of *that* class are: `"sandwich"`, `"1234"`, and `"name"`.

By virtue of being members of the same class of objects, we can operate on any string in exactly the same ways, regardless of the particular value an instance represents; for example: we can concatenate strings, we can use `len` to compute their length, we can loop over them with `for`, we can index into them to find the characters at particular locations within them, and we can convert them to lowercase with `x.lower()`. Importantly, it is the object's type that determines the operations that are possible when dealing with that object.

By creating our own types (or classes) of objects, we will be able to treat those custom data types as though they had been built in to Python. Throughout this reading, it will be important to draw a distinction between *creating a class* of objects, and *making an instance of that class*. When we talk about creating a class, we are talking about defining a whole new type of objects (including both how they are represented internally, and also the operations that are possible for that class of objects); when we talk about making an *instance* of a class, we are talking about making one particular object. For example, `list` is a class, and when we type `[1, 2, 3, 4]` into Python, we are making an instance of that class.

3) Custom Classes and Attributes

So far we've talked about this pretty abstractly; let's actually create our first class. Let's imagine that we are writing a program to perform some geometric calculations in 2-space.

In mathematical notation, points are often written in parentheses with a comma separating the coordinates. For example, $(0,0)$ represents the origin, and (x,y) represents the point x units to the right and y units up from the origin.

There are several ways we might represent points in Python:

- We could store the coordinates separately in two variables, `x` and `y`.
- We could store the coordinates as elements in a list or tuple.
- We could create a new type to represent points as objects.

In some ways, creating a new type is more complicated than the other options, but it has advantages that we will see soon.

A programmer-defined type is also called a *class*, and is defined using (perhaps unsurprisingly) the `class` keyword. Our first class definition looks like this:

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```
class Point:
    pass
```

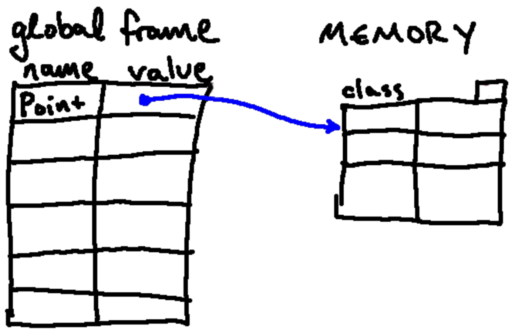
Class definitions always start with the `class` keyword, followed by a name for the class (here, `Point`), followed by an indented body. Class names are, by convention, capitalized.

For now, the body of this class definition is not particularly interesting: it consists of a single instruction to Python: `pass` (Python speak for *do nothing*). You can define variables and functions inside a class definition, but we will get back to that later.

Executing this definition causes Python to do two things: first, it creates a *class object* to represent this class; and second, it binds the name `Point` to this class object in the frame where the class was defined.

As always, we'll need a way to represent these new things in our environment diagrams. We'll represent class objects similarly to how we represent frames or dictionaries, but with a note to indicate that they are indeed classes.

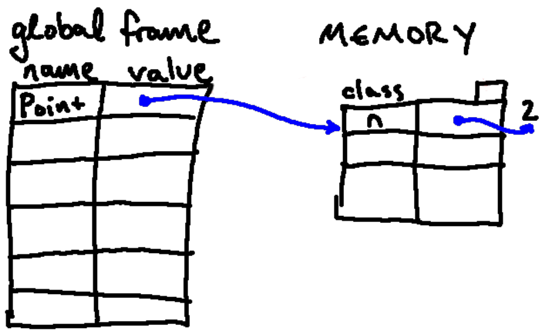
Evaluating the class definition above leaves us with the following environment diagram (notice that this statement both created the class object and associated the name `Point` with it):



When the class object is created, Python will execute the class body *within that environment*. It is possible to define variables within the class definition (typically, for things that are common to all instances of a class). For example, if we are only considering points in 2-space, we could have instead written:

```
class Point:
    # using a short variable name to represent the number of
    # coordinates so I can fit it in the environment diagram
    n = 2
```

which would result in the following environment diagram:



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We can look up and/or modify attributes within a class using the same dot notation we used for modules. For example, we could use the following:

```
print(Point.n)
```

To evaluate this expression, Python first looks up the name `Point` (finding the class object), and then it looks up the name `n` inside that object, finding the integer `2`. We could also perform assignment using similar notation:

```
Point.n = 3  # replaces the variable n inside the class
```

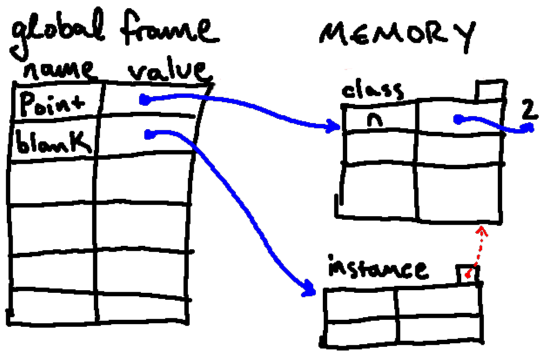
3.1) Creating Instances of User-Defined Classes

The class object is like a factory for creating objects. To create a Point, you call `Point` as if it were a function.

```
blank = Point()
```

The return value is a reference to a Point object, which we assign to `blank`. Creating a new object is called *instantiation*, and the object is an *instance* of the class.

We'll represent instances of user-defined classes in a similar fashion, except that we will label them as instances, and their parent pointers point back to their associated class. So evaluating the line above would result in the following environment diagram:



3.2) Attributes

You can assign values to an instance of a user-defined class using dot notation, the same way you would assign them within a class:

```
blank.x = 3.0
blank.y = 4.0
```

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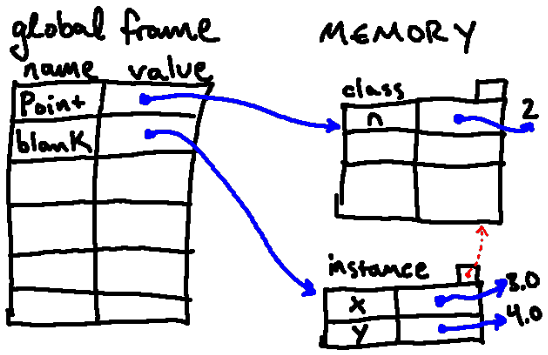
This syntax is similar to the syntax for selecting a variable from a module, such as `math.pi` or `string.whitespace`. In this case, though, we are assigning values to named elements of an object. These elements are called *attributes*[1] or *instance variables*.

The following diagram shows the result of executing these statements:



The variable `blank` refers to a Point object, which contains two attributes. Each attribute refers to a floating-point number.

You can read the value of an attribute using the same syntax:

```
print(blank.y)  # prints 4.0
x = blank.x
print(x)  # prints 3.0
```

Like we saw above with classes, the expression `blank.x` means "look up the name `blank` in the current frame, and look up the name `x` inside that object." In the example, we assign that value to a variable named `x`. There is no conflict between the variable `x` and the attribute `x` (because one is defined in the global frame, but the other is defined inside the instance).

You can use dot notation as part of any expression. For example:

```
print('(', blank.x, ',', blank.y, ')')  # prints ( 3.0 , 4.0 )

import math
distance = math.sqrt(blank.x**2 + blank.y**2)
print(distance)  # prints 5.0
```

3.2.1) Name Resolution

Notice that when we made our instance, we gave it a parent pointer to the class in which it was defined. With the syntax `blank.x`, we looked up the value of the name `x` inside the instance we had created. But what happens if we try to look up a name that does not exist?

Try Now:

What happens when you look up `blank.a`? What about `blank.n`?

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Looking up `blank.a` gives a new type of error: an `AttributeError`, saying that this object has no attribute `a`. Looking up `blank.n`, on the other hand, gives us `2`.

If Python is looking inside an object for an attribute and can't find it, it will look next in that object's class for that name. If it doesn't find it there, it will give an `AttributeError` (note that it will *not* continue looking beyond the class; i.e., it will not look in the global frame).

3.3) Example: Rectangles

Sometimes it is obvious what the attributes of an object should be, but other times you have to make decisions. For example, imagine you are designing a class to represent rectangles. What attributes would you use to specify the location and size of a rectangle? You can ignore angle; to keep things simple, assume that the rectangle is either vertical or horizontal.

There are at least two possibilities:

- You could specify one corner of the rectangle (or the center), the width, and the height.
- You could specify two opposing corners.

At this point it is hard to say whether either is better than the other, so we'll implement the first one, just as an example.

Here is the class definition:

```python
class Rectangle:
    pass
```

It doesn't look like much for now (because the body doesn't do anything).

Try Now:

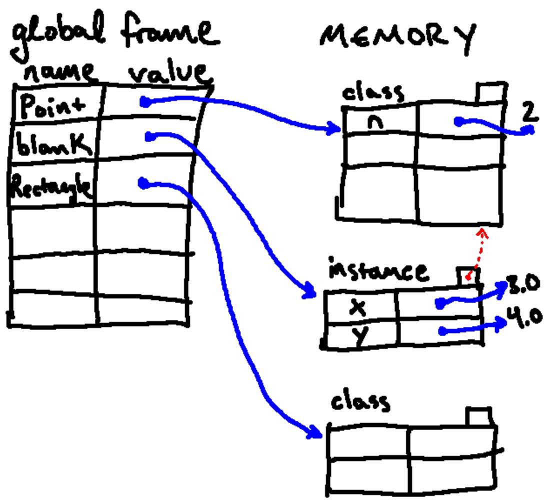
Draw the environment diagram that results from executing this statement, assuming that all of the below cod[Back to Top] also been executed.

```
class Point:
    n = 2

blank = Point()
blank.x = 3.0
blank.y = 4.0

class Rectangle:
    pass
```

Show/Hide



To represent a particular rectangle, you have to instantiate a Rectangle object and assign values to the attributes:

```
box = Rectangle()
box.width = 100.0
box.height = 200.0
box.corner = Point()
box.corner.x = 0.0
box.corner.y = 0.0
```

The expression `box.corner.x` means: "Go to the object `box` refers to and look up the attribute named `corner`; then go to that object and look up the attribute named `x`."

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Try Now:

Draw the environment diagram that results from executing the statements above.

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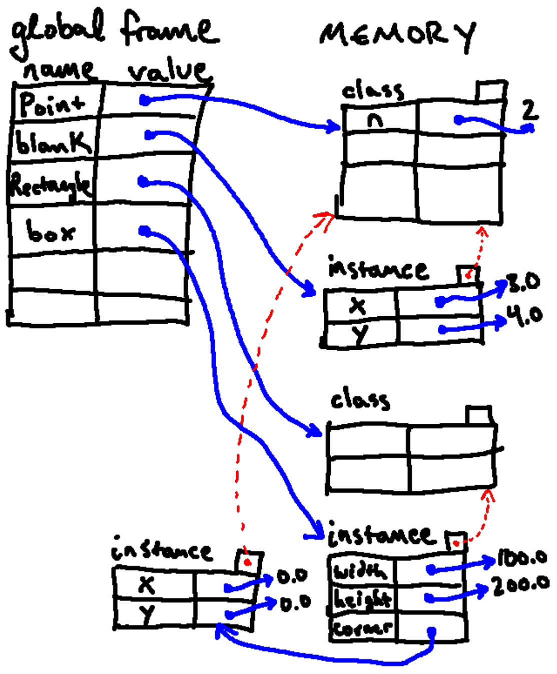
First, we create an instance of `Rectangle` and associated it with the name `box` in the global frame. Then we associate attributes `width` and `height` inside this instance with values `100.0` and `200.0`, respectively. Finally, we make a new instance of `Point`, associate it with the name `corner` inside the `Rectangle` instance, and associate attributes `x` and `y` in *that* (`Point`) instance with the values `0.0` and `0.0`, respectively.

It's starting to look a little like a bowl of spaghetti, but in the end, this results in the following diagram:



Try Now:

Using the environment diagram above, predict what will print to the screen if we run each of the following:

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```
print(box.width)
print(box.corner.x)
print(box.corner.n)
print(box.corner.box)
print(box.x)
```

Show/Hide

- The first will look up the name `box` in the global environment and then look up the name `width` inside that object, finding `100.0`.
- The second will look up the name `box` in the global environment, look up the name `corner` inside that object, and look up the name `x` inside *that* object, finding `0.0`.
- The third will look up the name `box` in the global environment, look up the name `corner` inside that object, and look up the name `n` inside *that* object. It does not find `n` inside of that object, so it looks inside its class (`Point`) and finds the value `2`.
- The fourth will not print anything, but will result in an error. Looking up `box.corner` finds the `Point` instance we created. We try to look up the name `box` inside that object and find nothing, so we look inside the class. In the class, we again don't find anything called `box`, so we give up and return an error. Importantly, we don't look for the name `box` in the global environment.
- The last will also result in an error, because the name `x` does not exist in the instance referred to by `box`, nor in its class (`Rectangle`).

4) Classes and Functions

We saw in the previous section that instances of user-defined classes can be treated like primitive objects. This means that we can also make functions that operate on instances, or that return new instances.

Functions can return instances of user-defined classes. For example, `find_center` defined below takes a `Rectangle` as an argument and returns a `Point` that contains the coordinates of the center of the `Rectangle`:

```
def find_center(rect):
    p = Point()
    p.x = rect.corner.x + rect.width/2
    p.y = rect.corner.y + rect.height/2
    return p
```

Here is an example that passes `box` as an argument and assigns the resulting Point to `center`:

```
center = find_center(box)
```

```
def print_point(p):
    print('(', p.x, ',', p.y, ')')

print_point(center)   # prints ( 50 , 100 )
```

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4.1) Functions that Modify Objects

We saw in the previous sections that objects are mutable. You can change the state of an object by making an assignment to one of its attributes. For example, to change the size of a rectangle without changing its position, you can modify the values of `width` and `height`:

```
box.width = box.width + 50
box.height = box.height + 100
```

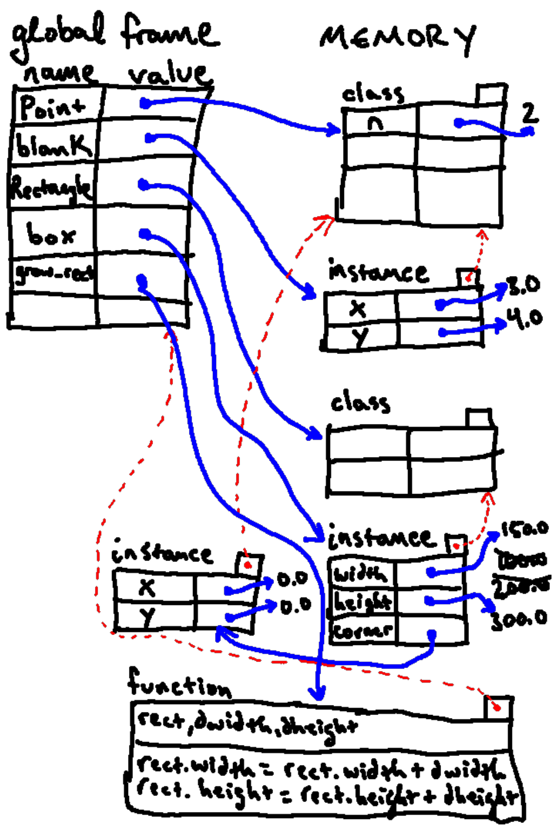
You can also write functions that modify objects. For example, `grow_rectangle` takes a Rectangle object and two numbers, `dwidth` and `dheight`, and adds the numbers to the width and height of the rectangle:

```
def grow_rectangle(rect, dwidth, dheight):
    rect.width = rect.width + dwidth
    rect.height = rect.height + dheight
```

Here is an example that demonstrates the effect:

```
print(box.width, box.height)  # prints 150.0 300.0
grow_rectangle(box, 50, 100)
print(box.width, box.height)  # prints 200.0 400.0
```

So how did this come to be? It's going to be a bit messy, but let's take a look at the environment diagram:



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Before we called `grow_rectangle`, we defined it in the global frame, resulting in the diagram above.

Try Now:

Write a function named `move_rectangle` that takes an instance of `Rectangle` and two numbers named `dx` and `dy`. It should change the location of the rectangle by adding `dx` to the `x` coordinate of `corner` and adding `dy` to the `y` coordinate of `corner`.

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Here is one solution:

```python
def move_rectangle(rect, dx, dy):
    rect.corner.x = rect.corner.x + dx
    rect.corner.y = rect.corner.y + dy
```

4.2) Pure Functions

It is also possible to define *pure functions* involving instances (that is, functions that do not modify their arguments, but return a new result).

For example, we could write a function like `move_rectangle`, but which creates a new instance representing the moBack to Top
rectangle, rather than mutating its input:

```
def shifted_rectangle(rect, dx, dy):
    new_rect = Rectangle()  # make a new instance
    # height and width should be the same
    new_rect.width = rect.width
    new_rect.height = rect.height
    # the corner of the rectangle is different, however
    new_rect.corner = Point()  # importantly, make a new instance of Point for the corner
    new_rect.corner.x = rect.corner.x + dx
    new_rect.corner.y = rect.corner.y + dy
    return new_rect
```

5) Classes and Methods

In the previous section, we saw examples of functions that operate on instances we've created. Similarly, we could define some new functions to define computations related to the `Point` class:

```
import math

def distance_to_origin(pt):
    return (pt.x**2 + pt.y**2)**0.5

def euclidean_distance(pt1, pt2):
    return ((pt1.x - pt2.x)**2 + (pt1.y - pt2.y)**2)**0.5

def manhattan_distance(pt1, pt2):
    return abs(pt1.x - pt2.x) + abs(pt1.y - pt2.y)

def add_vectors(pt1, pt2):
    new_pt = Point()
    new_pt.x = pt1.x + pt2.x
    new_pt.y = pt1.y + pt2.y
    return new_pt

def angle_between(pt1, pt2):
    vert = pt2.y - pt1.y
    horiz = pt2.x - pt1.x
    return math.atan2(vert, horiz)
```

However, just from looking at a program written in that style, it is not obvious that there is any connection between the functions we've defined, and the types of data they operate on. With some examination, however, it becomes apparent that all of the operations above take at least one instance of `Point` as an argument.

This observation is the motivation for *methods*. A *method* is a function that is associated with a particular class. Methods are semantically the same as functions, but there are two syntactic differences:

- Methods are defined inside a class definition in order to make the relationship between the class and the method explicit.

- The syntax for invoking a method is different from the syntax for calling a function.

Let's start by transforming one of these functions into a method. As a first step, all we have to do is to move the defi Back to Top the class (notice the change in indentation):

```
class Point:
    n = 2

    def distance_to_origin(pt):
        return (pt.x**2 + pt.y**2)**0.5
```

Once we have defined `distance_to_origin` this way, we now have two ways to call it. The first might seem familiar: if we have an instance `p` of point, we can look up the function with `Point.distance_to_origin`, and call it with `p` as an argument:

```
p = Point()
p.x = 3.0
p.y = 4.0

print(Point.distance_to_origin(p))  # prints 5.0
```

Using this notation, Python first looks up the name `Point`. It then looks up the name `distance_to_origin` inside that object, and calls the resulting function with the instance `p` passed in as an argument.

It turns out that people very rarely call methods using this syntax. Rather, we tend to use a more concise notation for calling methods:

```
print(p.distance_to_origin())  # also prints 5.0
```

This might seem weird! We defined `distance_to_origin` to take a single argument, but above, it seems not to be taking any! If this seems strange, that's normal. What we have here is a bit of "syntactic sugar:" syntax to make a common operation easier/sweeter to write.

In this slight shift of notation, `distance_to_origin` is still the name of the method we want to call, and its argument `p` is still the object the function acts on. Behind the scenes, though, if a method is looked up from an *instance* instead of from a *class*, Python will automatically insert that instance as the first argument to the method (so in this case the instance `p` is associated with the name `pt` inside the method body).

Note: In fact, we have seen this syntax before! When we used `append` to add elements to the end of a list `x`, we did it by saying `x.append(elt)`. But it turns out that we could also have done `list.append(x, elt)`.

By convention, the first parameter of a method is called `self`, so it would be more common to write `distance_to_origin` like this:

```
class Point:
    n = 2

    def distance_to_origin(self):
        return (self.x**2 + self.y**2)**0.5
```

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The reason for this convention is an implicit metaphor:

- The syntax for a function call, `distance_to_origin(pt)`, suggests that the function is the active agent. It says something like, "Hey `distance_to_origin`! Here's a point I want you to calculate the distance for."
- In this new shift of perspective (often referred to as *object-oriented programming*), the objects are the active agents. A method invocation like `p.distance_to_origin` says "Hey `p`! Please tell me your own distance to the origin."

This change in perspective might be more polite, but it is not obvious that it is useful. In the examples we have seen so far, it may not be. But sometimes shifting responsibility from the functions onto the objects makes it possible to write more versatile functions (or methods), and makes it easier to maintain and reuse code.

5.1) What is self?

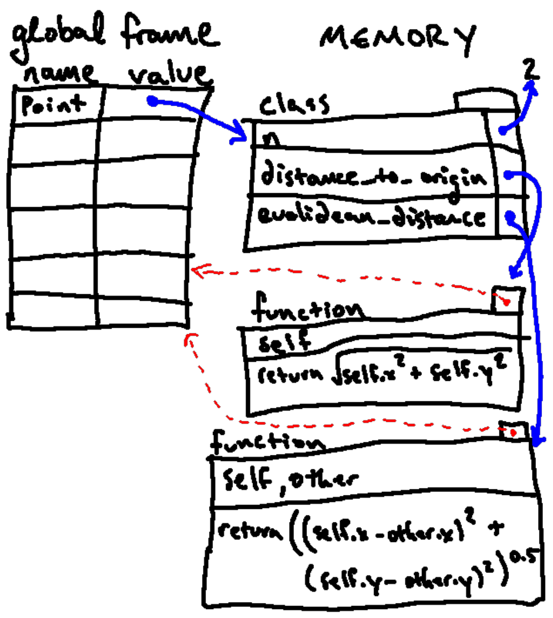
In this section, we'll expand a bit more on `self` (in Python, not philosophically!).

First, it's important to note that `self` is *just a name*, which is typically used as the first parameter to a method. This first argument, regardless of what it is called, always denotes *the instance that is currently being operated on*.

If a method is looked up via a *class*, it is up to the programmer to provide the instance of that class that the method should act on. If the method is looked up via an *instance*, however, Python will automatically insert that instance as the first argument to the method (the argument typically called `self`).

Let's expand on the definition of `Point` from above to include one more method, and then invoking a couple of methods:

```
class Point:
    n = 2

    def distance_to_origin(self):
        return (self.x**2 + self.y**2)**0.5

    def euclidean_distance(self, other):
        return ((self.x - other.x)**2 + (self.y - other.y)**2)**0.5

p1 = Point()
p1.x = 3.0
p1.y = 4.0

p2 = Point()
p2.x = 7.0
p2.y = 8.0

print(p1.distance_to_origin())
print(p2.euclidean_distance(p1))
```



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After the class definition, we have the diagram above. Note that `distance_to_origin` and `euclidean_distance` within the class object point to *functions*. Note also that these functions' parent pointers still point back to the *frame* in which they were defined (here, the global frame), even though they were defined inside a class.

Try Now:

Modify the `Point` definition to convert the other functions from above (`angle_between`, `manhattan_distance`, `add_vectors`) to methods. How would you call these methods from an instance `p` of `Point`?

5.1.1) Why is self Useful?

One reason `self` is useful is because it allows us to access and modify attributes from within a method. Whereas variables defined within a function are only accessible from that local frame, attributes defined inside of `self` will be accessible from other method calls, and, indeed, from outside the object!

This is important for objects with values unique to a particular *instance* across function calls (such as the `Point` class with `x` and `y`; or the `Rectangle` class with `corner`, `height`, and `width`).

6) The __init__ Method

In the previous examples, it was kind of a pain to make new instances of the classes we've defined; we had to first make the instance, and then bind new variables inside the resulting object.

The init method (short for "initialization") provides a means for easing this process. It is a special method that gets invoked when an object is instantiated. Its full name is `__init__` (two underscore characters, followed by `init`, and then two more underscores). An init method for the `Point` class might look like this:

```
class Point:

    def __init__(self, x, y):
        self.x = x
        self.y = y
```

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Once we have defined this method, we can create an instance like so:

```
mypoint = Point(2, 3)
```

If arguments are passed in when creating an instance of a class, Python will pass them to the class's `__init__` method. In particular, Python will do the following in response to the code above:

1. Create a new instance of `Point` and bind it to the name `mypoint`.
2. Run the `__init__` method with `mypoint` passed in as the first argument (in the example above, `Point.__init__(mypoint, 2, 3)`).
3. Inside of the body of the function, the name `self` refers to this new instance, so the function will store values `2` and `3` as `x` and `y`, respectively, inside the instance (so that they are accessible from outside the function as `mypoint.x` and `mypoint.y`).

It is common for the parameters of `__init__` to have the same names as the attributes. The statement:

```
        self.x = x
```

stores the value of the parameter `x` as an attribute of `self` (the newly-created instance).

7) Some Other "Magic" Methods

Python also has a number of other "magic" methods, which are called automatically by Python in certain situations, and which are typically denoted with a name surrounded by double-underscores. A more complete list is available here, but the following are a few examples:

- `__str__(self)` should return a string; this method is called when the instance in question is printed, or when converting to a string with the `str` function.
- `__add__(self, other)` is called when the `+` operator is used on two instances, allowing us to use the `+` operator on instances of our custom classes.
- `__mul__(self, other)` is called when the `*` operator is used on two instances.

As an example, consider printing one of the `Point` instances. Python will try its best to print a useful summary of the object, but the best it can do is something like:

```
p = Point(2, 3)
print(p)  # prints: <__main__.Point object at 0x7f8d7fae9d68>
```

Not very helpful at all! But if we define a `__str__` method first, we can get much nicer results:

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```
class Point:

    def __init__(self, x, y):
        self.x = x
        self.y = y

    def __str__(self):
        return "Point(" + str(self.x) + ", " + str(self.y) + ")"



p = Point(8, 4)
print(p)  # prints: Point(8, 4)
```

Try Now:

Earlier on, when we were talking about different representations for points, we listed three possibilities:

- storing `x` and `y` separately as two variables,
- storing coordinates in a list or tuple, or
- creating a new type to represent points as objects.

What are the benefits and drawbacks of each of these representations?

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Any of these representations could, in fact, work fine, but the representation of a point using a class has a number of nice features:

- It is easy to make multiple instances of the `Point` class, which would not be true of simply storing the `x` and `y` coordinates separately.
- Creating the `Point` class allows us to associate a number of methods specific to points with the objects themselves, rather than having them as separate stand-alone functions (which we would need if we were representing points as lists or tuples).

8) Extra Goodies

Now we switch to explaining some extra Python features. Ironically, one of the goals for this course has been to teach you as little Python as possible, in the sense that we wanted to focus on accurately modeling a small number of Python's features *which are not unique to Python*, and to provide a foundation on which future pieces can be added with relative ease.

Now we will go back for some of the good, relatively Python-specific bits that got left behind. Python provides a *lot* of features that are **not really necessary** (you can write good code to solve any problem without them), but with them you can sometimes write code that's more concise, readable, or efficient. You may have already seen many of these. We will now take the time to introduce them formally.

In this one section, there is not time to cover everything, but you will have plenty of time as you continue on with programming to pick up more and more of these little pieces!

8.1) "any" and "all"

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Python provides a built-in function, `any`, that takes a sequence of boolean values and returns `True` if any of the values are `True`. It works on lists:

```
print(any([False, False, True]))  # True
```

But it is often used with expressions like this:

```
print(any(letter == 't' for letter in 'monty'))  # True
```

That example isn't very useful because it does the same thing as the `in` operator. But we could use `any` to rewrite more complicated behaviors. For example, consider the following function:

```
def avoids(word, forbidden):
    for letter in word:
        if letter in forbidden:
            return False
    return True
```

We could have rewritten this function using `any`:

```
def avoids(word, forbidden):
    return not any(letter in forbidden for letter in word)
```

The function almost reads like English: "`word` avoids `forbidden` if there are not any forbidden letters in `word`."

Using `any` with a generator expression is efficient because it stops immediately if it finds a `True` value, so it doesn't have to evaluate the whole sequence.

Python provides another built-in function, `all`, that returns `True` if every element of the sequence is `True`. For example:

```
print(all([False, False, True]))  # False
nums = [2, 4, 6]
print(all(num % 2 == 0 for num in nums)) # True
```

8.2) Multiple Inline Comparisons

Earlier, we talked about Python's comparison operators (`>`, `<`, `>=`, `<=`, `==`, `!=`) as though they were binary operators, but it turns out that these are actually n-ary (that is, they can take more than 2 operands).

For example, we could write:

```
x < y < z
```

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which will evaluate to `True` only if `x` is less than `y` *and* `y` is less than `z`. This also works for the other comparators (and even for combinations of different comparators).

For example:

```
a == b == c  # evaluates to True if a == b and b == c
a > b < c  # evaluates to True if a > b and b < c
```

8.3) Error Handling

At some point when working on the exercises in this class, you may have encountered errors that were difficult to predict. In these cases, it would be nice to have a way for Python to detect that an error (in Python speak, an *exception* because it is not normal behavior) occurred, and to behave appropriately.

In some cases, rather than trying to *predict* errors, it is better to go ahead and try (and deal with problems if they happen), which is exactly what the `try` statement does. The syntax is similar to an `if`...`else` statement:

```
def safe_divide(x, y):
   try:
      return x / y  # this could result in a 'divide by zero' error
   except:
      print("Error in division!")
      return None
```

Python starts by executing the `try` body. If all goes well, it skips the `except` clause and proceeds. If an exception occurs, it jumps out of the `try` clause and runs the `except` clause.

Handling an exception with a `try` statement is called "catching" an exception. In this example, the except clause prints an error message that is not very helpful. In general, catching an exception gives you a chance to fix the problem, or try again, or at least end the program gracefully (rather than with a spew of Python-related red text).

9) Defining Functions - Lambda Notation

We've seen one line if/else statements and one line for loops, so you may be wondering if there are other one-line short cuts? Turns out the answer is yes! One "one-liner" that is sometimes useful is the `lambda` keyword, a convenient new way to define functions.

The most common way to define functions in Python, which we've already seen, is via the `def` keyword. For example, earlier we made a function that doubled its input, like so:

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

Recall that this will make a new function object in memory, and associate the name `double` with that object.

Python has another way of defining functions: the `lambda` keyword[2]. The below expression is also a function that doubles its input:

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```
lambda x: 2*x
```

The variable name(s) before the colon, here just `x`, are the names of the arguments. The expression after the colon is what the function will return.

This function is almost exactly the same as `double`, except that it does not have a name.

We could have used a `lambda` instead of a `def` when creating the response for `double` from above:

```
def response(f, lo, hi, step):
    out = []
    i = lo
    while i <= hi:
        out.append(f(i)) # here, we apply the provided function to i
        i += step
    return out

double_out = response(lambda x: 2*x, 0, 1, 0.1)
```

If we did not care about being able to access `double` outside of computing its response, it might make sense to do this. This is the same as passing a *function* in as the first argument to `response`; the function is just being defined with `lambda` instead of with `def`.

We could do the same to get the response for `square`:

```
square_out = response(lambda x: x**2, 0, 1, 0.1)
```

And we could have defined `add_n` as follows:

```
def add_n(n):
    return lambda x: x+n
```

You can also define functions of more than one argument using `lambda`s. Both of the below pieces of code define `multiply` to be a function which returns the multiplication of its two inputs, for example:

```
def multiply(a, b):
    return a*b
```

```
multiply = lambda a, b: a*b
```

You should know that `lambda`, while sometimes a nice convenience, is never necessary—you can **always** use `def` instead!

Similar to the list comprehension syntax we'll explore below in section 6, the `lambda` syntax is less explicit about what Python is doing than its `def` counterpart, and it's harder to debug since it cannot include `print` statements. As such, use it sparingly, and only when the function body is simple (e.g., a one-line return statement).

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9.1) Enumerate

Have you ever wanted to both index and get the element from a list? Well Python has an `enumerate` function that will do just that.[3]

```
seasons = ['Spring', 'Summer', 'Fall', 'Winter']

for i in range(len(seasons)):
    season = seasons[i]
    print(i, season)

# can be written more succinctly with enumerate:
for i, season in enumerate(seasons):
    print(i, season)

print(list(enumerate(seasons)))
# [(0, 'Spring'), (1, 'Summer'), (2, 'Fall'), (3, 'Winter')]
```

`enumerate` can take any iterable as an argument (anything that can be looped over!)

9.2) Zip

Have you ever wanted to get the corresponding elements from separate lists? Well Python's `zip` function that will do just that.

```
first = ['Tim', 'Duane', 'Hope', 'Jeff']
last = ['Beaver', 'Boning', 'Dargan',]

smaller = min(len(first), len(last))
for i in range(smaller):
    fname = first[i]
    lname = last[i]
    print(fname, lname)

# with zip:
for fname, lname in zip(first, last):
    print(fname, lname)

print(list(zip(first, last))) # [('Tim', 'Beaver'), ('Duane', 'Boning'), ('Hope', 'Dargan')]
```

`zip` will take any number of iterable (loopable) arguments and produce tuples of the corresponding elements in order (cutting off at the end of the shortest argument). You can read more about `zip` and other built-in functions by reviewing Python's documentation here.

10) Python Goodies Review

While prior readings have covered these topics, the following sections offer some review that may be helpful:

10.1) Sequence Unpacking

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It is often useful to swap the values of two variables. With conventional assignments, you have to use a temporary variable. For example, to swap `a` and `b`:

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

This solution is cumbersome; *tuple assignment* is more elegant:

```
a, b = b, a
```

The left side is a tuple of variables; the right side is a tuple of expressions. Each value is assigned to its respective variable. All the expressions on the right side are evaluated before any of the assignments.

The number of variables on the left and the number of values on the right have to be the same:

```
a, b = 1, 2, 3  # this produces: ValueError: too many values to unpack
```

This error message might seem weird, but this idea of assigning each element in a sequence to a different variable name is often referred to as *unpacking* that sequence.

For example, consider the following three pieces of code to compute the distance between points (where points are represented as `(x, y)` tuples.

```
def distance(pt1, pt2):
    return ((pt1[0] - pt2[0])**2 + (pt1[1] - pt2[1])**2)**0.5

def distance(pt1, pt2):
    x1 = pt1[0]
    y1 = pt1[1]
    x2 = pt2[0]
    y2 = pt2[1]
    return ((x1 - x2)**2 + (y1 - y2)**2)**0.5

def distance(pt1, pt2):
    x1, y1 = pt1
    x2, y2 = pt2
    return ((x1 - x2)**2 + (y1 - y2)**2)**0.5
```

The first function definition is nice and to-the-point, but it is a bit hard to read because the indexing operations are all collapsed together with the mathematical operation to compute the distance. The second makes the last line easier to read, but at the expense of having to write 4 extra lines of code. The last, I think, strikes a nice balance between the two.

More generally, the right side can be any kind of sequence (string, list or tuple). For example, to split an email address into its username and domain name, we could do:

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```
address = 'a_clever_username@mit.edu'
uname, domain = address.split('@')
```

The return value from `split` is a list with two elements; the first element is assigned to `uname`, the second to `domain`.

```
print(uname)  # prints a_clever_username
print(domain)  # prints mit.edu
```

10.2) Generating Graphs with matplotlib

The `matplotlib.pyplot` module provides a number of useful functions for creating plots with Python. In this section we'll go over a few examples of how to generate different plots.

To import the `pyplot` module, add the following to the top of your script:

```
import matplotlib.pyplot as plt
```

Once you have done so, you can make a new plot by calling `plt.figure()` with no arguments. After that, you can use various functions to add data to the figures. When you are ready, calling the `plt.show()` function with no arguments will cause `matplotlib` to open windows displaying the resulting graphs. You can also add a legend and/or a title to the plot, as well as labels to the axes, as shown in the example below.

The following code will cause four windows to be displayed. Try running the code below on your own machine to see the results. Notice that the `plt.show()` function does not return until the plotting windows are closed.

```
import matplotlib.pyplot as plt

# here we plot a set of "y" values only; these are associated automatically
# with integer "x" values starting with 0.
plt.figure()
plt.plot([9, 4, 7, 6])

# if given two arguments, the first list/array will be used as the "x" values,
# and the second as the associated "y" values
plt.figure()
plt.plot([10, 9, 8, 7], [1, 2, 3, 4])
plt.grid()  # this adds a background grid to the plot

# we can also create scatter plots.  scatter plots require both "x" and "y"
# values.
plt.figure()
plt.scatter([10,25, 37, 42], [12, 28, 5, 37])

# multiple calls to plt.plot or plt.scatter will operate on the same axes
plt.figure()
plt.scatter([10, 25, 37, 42], [12, 28, 5, 37], label='scatter')
plt.plot([10, 40], [5, 20], 'r', label='a line') # the 'r' means 'red'
plt.plot([5, 9, 15, 30], [10, 20, 30, 35], 'k', label='more data')
plt.title('A more complete example')
plt.xlabel('A label for x')
plt.ylabel('The vertical axis')
plt.legend()

# finally, display the results
print('Showing Graphs')
plt.show()
print('Done')
```

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10.3) Slicing

You've seen before that it's possible to "index into" sequences (strings, lists, tuples) to extract particular values from them. It is also possible to select a segment (called a *slice*) of the sequence using a similar syntax.

Consider the following example using strings:

```
fruit = 'banana'
print(fruit[0:4])  # prints bana
print(fruit[2:4])  # prints na
```

The *slicing* operator `[start:stop]` returns the part of the string from the $start^{\text{th}}$-indexed character to the $stop$-index character, including the first but excluding the last.

If you omit the first index (before the colon), the slice starts at the beginning of the string. If you omit the second index, the slice goes to the end of the string:

```
print(fruit[:3])  # prints ban
print(fruit[3:])  # prints ana
```

If the first index is greater than or equal to the second the result is an empty string, represented by two quotation marks:

```
print(fruit[3:3])  # this results in the empty string `''`
```

An empty string contains no characters and has length 0, but other than that, it is the same as any other string.

Continuing this example, what do you think `fruit[:]` means? Try it and see.

The slicing operator (similarly to the `range` function) also takes an optional third argument (commonly referred to as `step`), which specifies how many characters to 'skip' on each step. If it is not specified, this value defaults to `1`.

In its full form, this operator looks like `[start:stop:step]`. For example:

```
print(fruit[::2])  # bnn
print(fruit[0:4:3])  # ba
print(fruit[1::3])  # an
```

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These numbers can sometimes be a bit confusing; it helps to think about this operator in terms of how it would be defined as a function:

```
def slice(string, start, stop, step):
    out = ''
    index = start
    while index < stop:
        out += string[index]
        index += step
    return out
```

Notice that step can be negative, which gives us an easy way to make a *reversed* version of a given sequence:

```
print(fruit[::-1])
```

The slice operator also works on lists:

```
t = ['a', 'b', 'c', 'd', 'e', 'f']
print(t[1:3])  # ['b', 'c']
print(t[:4])  # ['a', 'b', 'c', 'd']
print(t[3:])  # ['d', 'e', 'f']
```

If you omit the first index, the slice starts at the beginning. If you omit the second, the slice goes to the end. So if you omit both, the slice is a copy of the whole list.

```
print(t[:])  # ['a', 'b', 'c', 'd', 'e', 'f']  (but this is a DIFFERENT list containing the same elements)
```

Since lists are mutable, it can sometimes be useful to make a copy before performing operations that modify lists.

A slice operator on the left side of an assignment can update multiple elements:

```
t = ['a', 'b', 'c', 'd', 'e', 'f']
t[1:3] = ['x', 'y']
print(t)  # ['a', 'x', 'y', 'd', 'e', 'f']
```

10.4) Optional Arguments to Functions

When defining a function, one sometimes want to be able to call the function with a particular argument, but also without it. For this, there are optional arguments. Consider this example:

```
def approximately_equal(x, y, threshold=0.1):
    return abs(x - y) <= threshold
```

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If `threshold` is specified (e.g., `approximately_equal(x, y, 1e-6)`), then that value will be used for `threshold` (in this case, 10^{-6}). If not (e.g., `approximately_equal(x, y)`), then the default value (`0.1`) will be used for `threshold`.

In other words, if we provide the optional argument, it *overrides* the default value.

If a function has both required and optional parameters, all the required parameters have to come first, followed by the optional ones.

There is a small caveat here (and often a *big* source of bugs): default values are evaluated at the time the function is *defined*, not when the function is called. So we have to be careful when using a mutable object as a default value for a parameter; if we do this, all calls to the function will use that same object (which may have been modified by previous calls).

10.5) Filtering List Comprehensions

Earlier, we saw how to use the concise list comprehension syntax to create a list based on another sequence. List comprehensions can also be used for filtering.

For example, if we had a list and we wanted to find the squares of the odd numbers in that list, we could do:

```
def squared_odd_numbers(input_list):
    out = []
    for i in input_list:
        if i % 2 == 1:  # if i is odd
            out.append(i ** 2)
    return out
```

or, using a list comprehension:

```
def squared_odd_numbers(input_list):
    return [i**2 for i in input_list if i % 2 == 1]
```

This functions selects only the elements from `input_list` that are odd, squares them, and returns a new list containing the result.

10.6) Ternary Conditional Expressions

You may want to set a variable to one thing if a certain condition is true, and another otherwise:

```
if my_condition:
    x = a
else:
    x = b
```

This is a lot of lines for a simple task. It turns out you can write the above like so:

```
x = a if my_condition else b
```

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The expression on the right hand side evaluates to `a` if `my_condition` is `True`; otherwise, it evaluates to `b`. The overall statement is an assignment statement, so that `a` or `b` is assigned to the variable `x`.

11) Summary

In this set of readings, we first learned about a powerful new feature of Python: *classes*, which allowed us to define new *types* of Python objects. Just as functions allowed us to abstract away details of particular *operations* and treat them as though they had been built in to Python, classes let us abstract away details of particular *data types* and treat them as though they were built in to Python.

Then we also shared a bunch of concise syntax features of Python.

Next Exercise: Things

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Footnotes

1 As a noun, "AT-trib-ute" is pronounced with emphasis on the first syllable, as opposed to "a-TRIB-ute", which is a v Back to Top

2 This may seem like a bizarre name, but it comes from a mathematical system for expressing computation, called the Lambda calculus.

3 The example below comes from Python's official documentation for enumerate