Classes and Object 1

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Classes and Objects

- Imperative programming manipulates the state of memory
  - Breaks up tasks through procedures and functions
- Object Oriented Programming
  - Creates objects that interact with each other
  - Objects are defined with a user-defined data type

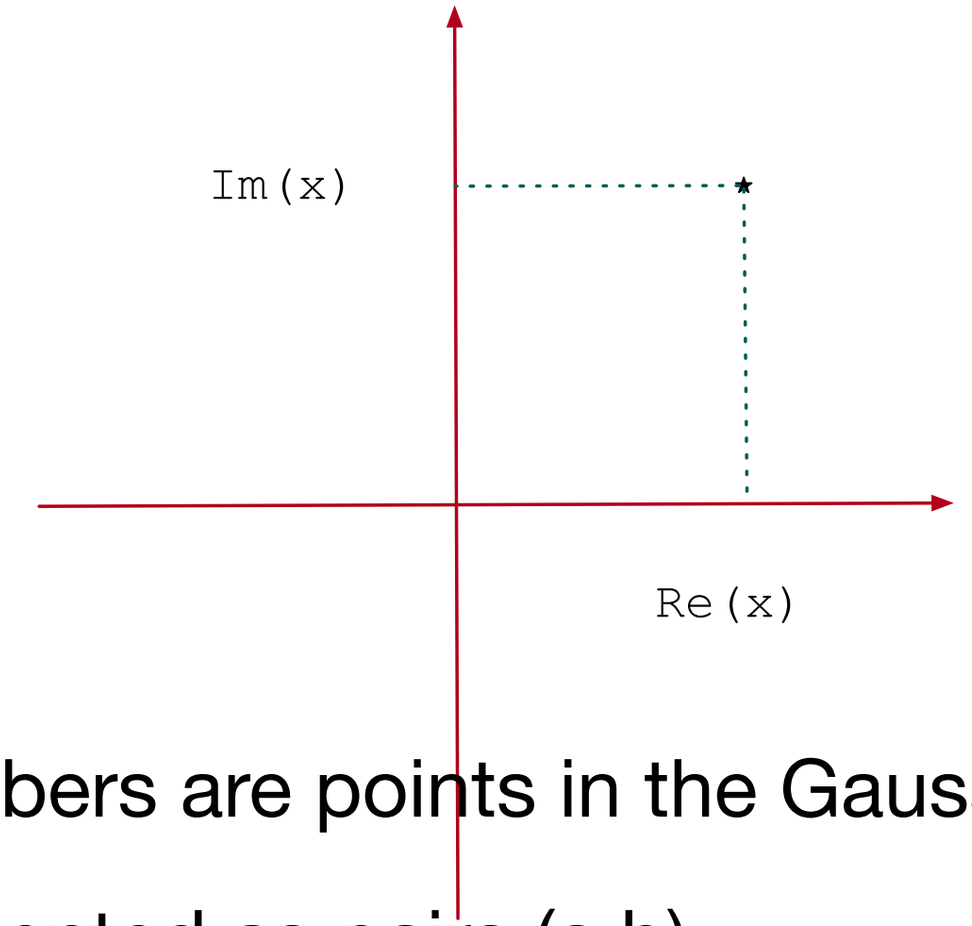
Classes and Objects

- Each object maintains its own state
  - Objects manipulate themselves and other objects through methods

Classes and Objects

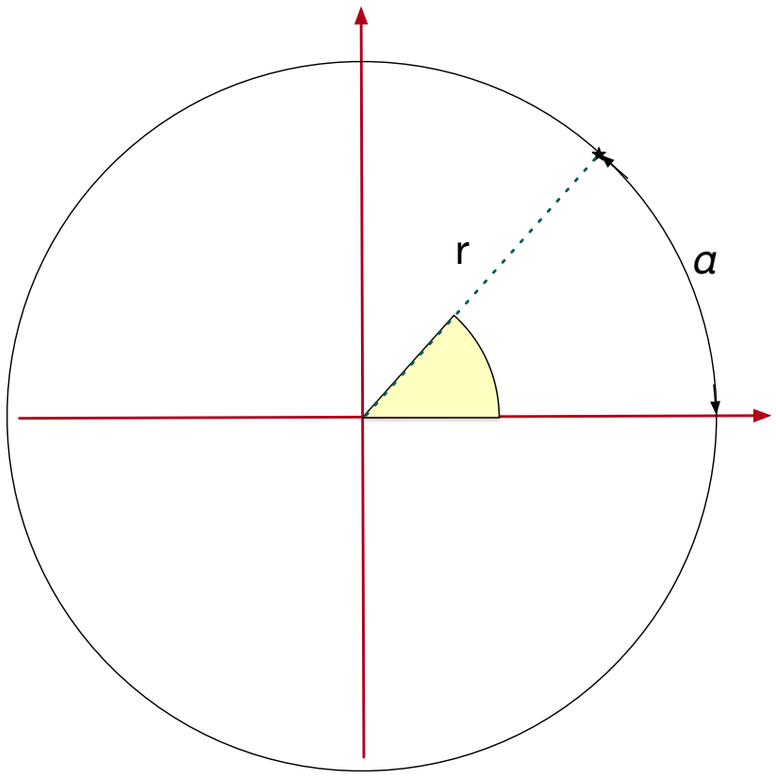
- Running Example:
  - Complex Numbers
  - Complex numbers live in the complex plane
  - Two canonicals way of representing them:
  - Via coordinates (the real and the imaginary part)
  - Via length and angle to x-axis

Complex Numbers



- Complex numbers are points in the Gaussian plane
- Can be represented as pairs (a,b)
  - a is called the real part, b is called the imaginary part
  - Written as `a+ib,` the “algebraic notation”

Complex Numbers



r is the length
α is the phase in radians

- Polar form
  - Given by angle α with x-axis and a length r
  - Written as $r \cdot e^{i\alpha}$

Complex Numbers

- Complex numbers allow various operations such as addition, multiplication, exponentiation,
- The have a length, a real part, and imaginary part, and a phase
- They have a transpose
- And so much more

OOP in Python

- We define the type of an object as a class
  - Objects have fields and methods
    - Fields are like variables
    - Methods are like functions

- A complex number has two fields: the real and the imaginary part
- A method would be the calculation of the length
- Another standard method would be a string describing the number

OOP in Python

- There are two types of fields and methods:
  - Those that belong to the class:
    - Class variables (aka Class fields), Class methods
  - And those that belong to an object
    - Object variables, Object methods

OOP in Python

- To create an object of type class, **“instantiation”**: we define and use an initializer called `__init__()`
- The initializer can have arguments.
- If we create object variables and methods, we use the (quasi-)keyword `self` to refer to the object.

OOP in Python

The double underscore before and after make this a reserved method name.

```
class Complex():
    def __init__(self, real, imaginary):
        self.re = real
        self.im = imaginary
    def __str__(self):
        return "{}+i{}".format(self.re, self.im)

if __name__ == "__main__":
    a = Complex(-2, 3)
    b = Complex(1, 2)
    print(a, b)
```

They are called dunder methods.

OOP in Python

The “self” is required. It renders this is an instance method

```
class Complex():
    def __init__(self, real, imaginary):
        self.re = real
        self.im = imaginary
    def __str__(self):
        return "{}+i{}".format(self.re, self.im)

if __name__ == "__main__":
    a = Complex(-2, 3)
    b = Complex(1, 2)
    print(a, b)
```

OOP in Python

The real and imaginary are parameters

```
class Complex():
    def __init__(self, real, imaginary):
        self.re = real
        self.im = imaginary
    def __str__(self):
        return "{}+i{}".format(self.re, self.im)

if __name__ == "__main__":
    a = Complex(-2, 3)
    b = Complex(1, 2)
    print(a, b)
```

OOP in Python

```
class Complex():
    def __init__(self, real, imaginary):
        self.re = real
        self.im = imaginary
    def __str__(self):
        return "{}+i{}".format(self.re, self.im)

if __name__ == "__main__":
    a = Complex(-2, 3)
    b = Complex(1, 2)
    print(a, b)
```

This is the creation of an instance of the class. “self” is hidden, -2 is real and 3 is imaginary

OOP in Python

This defines an instance field called “re”

```
class Complex():
    def __init__(self, real, imaginary):
        self.re = real
        self.im = imaginary
    def __str__(self):
        return "{}+i{}".format(self.re, self.im)

if __name__ == "__main__":
    a = Complex(-2, 3)
    b = Complex(1, 2)
    print(a, b)
```

OOP in Python

This defines an instance field called “im”

```
class Complex():
    def __init__(self, real, imaginary):
        self.re = real
        self.im = imaginary
    def __str__(self):
        return "{}+i{}".format(self.re, self.im)

if __name__ == "__main__":
    a = Complex(-2, 3)
    b = Complex(1, 2)
    print(a, b)
```

OOP in Python

Assigning self.whatever anywhere in the definition of the class will create an instance object

```
class Complex():
    def __init__(self, real, imaginary):
        self.re = real
        self.im = imaginary
    def __str__(self):
        return "{}+i{}".format(self.re, self.im)

if __name__ == "__main__":
    a = Complex(-2, 3)
    b = Complex(1, 2)
    print(a, b)
```

OOP in Python

The two underscores before and after denotes __str__ as a reserved name.

```
class Complex():
    def __init__(self, real, imaginary):
        self.re = real
        self.im = imaginary
    def __str__(self):
        return "{}+i{}".format(self.re, self.im)

if __name__ == "__main__":
    a = Complex(-2, 3)
    b = Complex(1, 2)
    print(a, b)
```

OOP in Python

__str__ takes the instance and creates a string. The string should reflect the contents of the object.

```
class Complex():
    def __init__(self, real, imaginary):
        self.re = real
        self.im = imaginary
    def __str__(self):
        return "{}+i{}".format(self.re, self.im)

if __name__ == "__main__":
    a = Complex(-2, 3)
    b = Complex(1, 2)
    print(a, b)
```

OOP in Python

When `print` is called on objects of type complex, then Python looks first for a __str__ method and then for a __repr__ method. The __repr__ method is supposed to give more details for debugging.

```
class Complex():
    def __init__(self, real, imaginary):
        self.re = real
        self.im = imaginary
    def __str__(self):
        return "{}+i{}".format(self.re, self.im)

if __name__ == "__main__":
    a = Complex(-2, 3)
    b = Complex(1, 2)
    print(a, b)
```

OOP in Python

- Adding Methods
  - Every complex number has a length:

$$|a + bi| = \sqrt{a^2 + b^2}$$

  - To create a method calculating the length:
    - We need one argument: the object (the complex number) itself
    - This argument is called `self`

```
class Complex():
    def __init__(self, real, imaginary):
        self.re = real
        self.im = imaginary
    def __str__(self):
        if self.re==0 and self.im==0:
            return "0"
        if self.re==0 and self.im>0:
            return "i{}".format(self.im)
        if self.re==0 and self.im<0:
            return "-i{}".format(-self.im)
        if self.im<0:
            return "{}-i{}".format(self.re, -self.im)
        if self.im>0:
            return "{}+i{}".format(self.re, self.im)
        return str(self.re)
    def length(self):
        return math.sqrt(self.re*self.re+self.im*self.im)


if __name__ == "__main__":
    a = Complex(-2, 3)
    print(a.length())
```

The one argument is self

```
class Complex():
    def __init__(self, real, imaginary):
        self.re = real
        self.im = imaginary
    def __str__(self):
        if self.re==0 and self.im==0:
            return "0"
        if self.re==0 and self.im>0:
            return "i{}".format(self.im)
        if self.re==0 and self.im<0:
            return "-i{}".format(-self.im)
        if self.im<0:
            return "{}-i{}".format(self.re, -self.im)
        if self.im>0:
            return "{}+i{}".format(self.re, self.im)
        return str(self.re)
    def length(self):
        return math.sqrt(self.re*self.re+self.im*self.im)


if __name__ == "__main__":
    a = Complex(-2, 3)
    print(a.length())
```

Here is how this function is called: The object is followed by a period

```
class Complex():
    def __init__(self, real, imaginary):
        self.re = real
        self.im = imaginary
    def __str__(self):
        if self.re==0 and self.im==0:
            return "0"
        if self.re==0 and self.im>0:
            return "i{}".format(self.im)
        if self.re==0 and self.im<0:
            return "-i{}".format(-self.im)
        if self.im<0:
            return "{}-i{}".format(self.re, -self.im)
        if self.im>0:
            return "{}+i{}".format(self.re, self.im)
        return str(self.re)
    def length(self):
        return math.sqrt(self.re*self.re+self.im*self.im)


if __name__ == "__main__":
    a = Complex(-2, 3)
    print(a.length())
```

So, this method is really a function of one argument, even if it does not look like it.

```
class Complex():
    def __init__(self, real, imaginary):
        self.re = real
        self.im = imaginary
    def __str__(self):
        if self.re==0 and self.im==0:
            return "0"
        if self.re==0 and self.im>0:
            return "i{}".format(self.im)
        if self.re==0 and self.im<0:
            return "-i{}".format(-self.im)
        if self.im<0:
            return "{}-i{}".format(self.re, -self.im)
        if self.im>0:
            return "{}+i{}".format(self.re, self.im)
        return str(self.re)
    def length(self):
        return math.sqrt(self.re*self.re+self.im*self.im)


if __name__ == "__main__":
    a = Complex(-2, 3)
    print(a.length())
```

Here we are referring to an instance field.

Self Test:

Stop the presentation and fire up IDLE

- The phase of a complex number is defined by

$$\textbf{arg}(a+bi) = \begin{cases} \arctan(\frac{b}{a}) & \textbf{if } a > 0 \\ \arctan(\frac{b}{a}) + \pi & \textbf{if } a < 0 \textbf{ and } b \geq 0 \\ \arctan(\frac{b}{a}) - \pi & \textbf{if } a < 0 \textbf{ and } b < 0 \\ \frac{\pi}{2} & \textbf{if } a = 0 \textbf{ and } b > 0 \\ -\frac{\pi}{2} & \textbf{if } a = 0 \textbf{ and } b < 0 \\ \textbf{undefined} & \textbf{if } x = 0 \textbf{ and } b = 0 \end{cases}$$

- Raise a ValueError in the last case, the arctan in the math library is called atan.

```
class Complex():
    def arg(self):
        if self.re == 0 and self.im == 0:
            raise ValueError
        if self.re > 0:
            return math.atan(self.im/self.re)
        if self.re < 0 and self.im >= 0:
            return math.atan(self.im/self.re)+math.pi
        if self.re < 0 and self.im < 0:
            return math.atan(self.im/self.re) - math.pi
        if self.re == 0 and self.im > 0:
            return math.pi/2
        if self.re == 0 and self.im < 0:
            return -math.pi/2

if __name__ == "__main__":
    a = Complex(0, 0)
    print(a.arg())
```

OOP in Python

- Methods can of course return other objects
  - The conjugate of a complex number is obtained by reflecting around the y-axis

$$a + bi = a - bi$$

OOP in Python

```
class Complex():
    def conjugate(self):
        return Complex(self.re, -self.im)
```

```
if __name__ == "__main__":
    a = Complex(2, 3)
    print(a.conjugate())
```

OOP

- Python knows “operator overloading”
  - Instead of adding two complex numbers by saying something like `c=add(a,b)`
  - We can say `c=a+b`

- Python knows a number of such overloads and associates them by reserving function names

```
class Complex():
    def __add__(self, other):
        return Complex(self.re+other.re, self.im+other.im)

if __name__ == "__main__":
    a = Complex(2, 3)
    b = Complex(3, -5)
    print(a+b)
```

We need to return a complex number

Here we are adding two complex numbers.

Self Test

- Overload the subtraction
  - The reserved method name is __sub__
    - (Two underscores before and after)

Solution

```
class Complex():
    def __sub__(self, other):
        return Complex(self.re-other.re, self.im-other.im)

if __name__ == "__main__":
a = Complex(2, 3)
b = Complex(3, -5)
suma = a+b
dif = a-b
print(a, b, suma, dif)
```

OOP in Python

- We can define comparisons via overloading
  - For equality, the reserved method name is __eq__

OOP in Python

- Resolving operators
  - Operator overloading does not have to happen between objects of the same type
  - If there is an expression `a==b`
    - Python first looks into the class definition of a for an __eq__ method that has second parameter the type of b
    - If that fails, Python then looks into the class definition of b for an __eq__method

OOP

- In fact, there is a default comparison between two objects
  - It is based on *IDENTITY* ***NOT*** *EQUALITY*
  - Identity: Two objects are stored at the same location
  - Equality: Two objects have the same fields

```
class Complex():
    def __eq__(self, other):
        if isinstance(other, Complex):
            return self.re==other.re and self.im==other.im
        return NotImplemented
    def __ne__(self, other):
        if isinstance(other,Complex):
            return self.re!=other.re or self.im!=other.im
        return NotImplemented

if __name__ == "__main__":
    a = Complex(2, 3)
    b = Complex(3, -5)
    print(a==b, a!=b)
    print(a==Complex(2,3), a!=Complex(2,3))
```

We only want to compare two complex numbers

```
class Complex():
    def __eq__(self, other):
        if isinstance(other, Complex):
            return self.re==other.re and self.im==other.im
        return NotImplemented
    def __ne__(self, other):
        if isinstance(other,Complex):
            return self.re!=other.re or self.im!=other.im
        return NotImplemented

if __name__ == "__main__":
a = Complex(2, 3)
b = Complex(3, -5)
print(a==b, a!=b)
print(a==Complex(2,3), a!=Complex(2,3))
```

Two complex numbers are equal if they have the same real and imaginary parts

```
class Complex():
    def __eq__(self, other):
        if isinstance(other, Complex):
            return self.re==other.re and self.im==other.im
        return NotImplemented
    def __ne__(self, other):
        if isinstance(other,Complex):
            return self.re!=other.re or self.im!=other.im
        return NotImplemented

if __name__ == "__main__":
a = Complex(2, 3)
b = Complex(3, -5)
print(a==b, a!=b)
print(a==Complex(2,3), a!=Complex(2,3))
```

If we compare a complex number with a non-complex number then we want to return the constant `NotImplemented`

Classes and Objects

- Classes usually define objects, but they can also used in isolation
  - Assume that you want to use a number of global variables
    - This is dangerous, since you might be reusing the same name
- Solution: Use a class that contains all these variables

A Globals Class

- We call the class Gl — short for global
- Store constants as class variables

```
class Gl:
    gr2gr = 0.06479891
    dr2gr = 1.7718451953125
    oz2gr = 28.349523125
    lb2gr = 453.59237
    st2gr = 6350.29318
```

- Easy to identify in program

```
def translate(number, measure):
    if measure == "gr":
        return "{0:.3f} {1}".format(number*Gl.gr2gr, "gram")
    if measure == "dr":
        return "{0:.3f} {1}".format(number*Gl.dr2gr, "gram")
    if measure == "oz":
        return "{0:.3f} {1}".format(number*Gl.oz2gr, "gram")
    if measure == "lb":
        return "{0:.3f} {1}".format(number*Gl.lb2gr, "gram")
    if measure == "st":
        return "{0:.3f} {1}".format(number*Gl.st2gr/1000, "kg")
    raise ValueError
```

Class and Instance Variables

- Class variable
  - belong to the class
  - shared by all objects
  - defined without prefix in the class
- Instance variable
  - belong to the instance
  - not shared by objects
  - defined by using an object or self prefix

Self Test

- Identify the type of the bold-faced variables in the following code

```
import math

class Example:
    exists = False
    def __init__(self, x, y):
        self.radius = math.sqrt(x*x+y+y)
        self.x = x
        self.y = y
        Example.exists = True

print(Example.exists)
e = Example(2, 3)
print(e.x)
print(Example.exists)
print(e.radius)
```

Answer

```
import math

class Example:
    exists = False
    def __init__(self, x, y):
        self.radius = math.sqrt(x*x+y+y)
        self.x = x
        self.y = y
        Example.exists = True

print(Example.exists)
e = Example(2, 3)
print(e.x)
print(Example.exists)
print(e.radius)
```

This is an instance variable. It belongs to the (one and only) object of type Example.

It happens to be defined in __init__. However, it is defined with the self prefix.

Answer

```
import math

class Example:
    exists = False
    def __init__(self, x, y):
        self.radius = math.sqrt(x*x+y+y)
        self.x = x
        Example.exists = True

print(Example.exists)
e = Example(2, 3)
print(e.x)
print(Example.exists)
print(e.radius)
```

This is a class variable. It is specified by using the class name “Example.”

It is defined without a prefix within the class.

Answer

```
import math

class Example:
    exists = False
    def __init__(self, x, y):
        self.radius = math.sqrt(x*x+y+y)
        self.x = x
        self.y = y
        Example.exists = True

print(Example.exists)
e = Example(2, 3)
print(e.x)
print(Example.exists)
print(e.radius)
```

This is an instance variable. It is defined with the prefix self.

It is used by referring to an object e.

Class and Instance Methods

- The same distinction can be made for methods
  - Methods are functions related to an object
- A class method depends only on the class.
  - It is defined in the class, but has no argument self
  - It is called by giving the class-name
- An instance method depends on an instance
  - It is defined in the class with first argument `self`
  - It is called by prefacing it with an instance.
    - The instance is called the implicit argument

Class and Instance Methods

```
class Example:
    def foo():
        print("foo")
    def __init__(self):
        pass
    def bar(self):
        print("bar")

Example.foo()
e = Example()
e.bar()
```

A method definition without argument self: Class Method

It is called using the class-name to call it

Class and Instance Methods

```
class Example:
    def foo():
        print("foo")
    def __init__(self):
        pass
    def bar(self):
        print("bar")

Example.foo()
e = Example()
e.bar()
```

A method definition with argument self: Instance Method

It is called using the Instance. Without an object e, we cannot call it.

Self Test

- Identify the type of methods in the following code

```
import math
class Vector3D:
    def __init__(self, x, y, z):
        self.x = x
        self.y = y
        self.z = z
    def zeroes():
        return Vector3D(0,0,0)
    def ones():
        return Vector3D(1,1,1)
    def __add__(self, other):
        return Vector3D(self.x+other.x,
                        self.y+other.y,
                        self.z+other.z)
    def __str__(self):
        return "({}, {}, {})".format(self.x, self.y, self.z)
    def length(self):
        return math.sqrt(self.x**2+self.y**2+self.z**2)
```

Answers

Dunder (double under) method:
Hard to tell

```
import math
class Vector3D:
    def __init__(self, x, y, z):
        self.x = x
        self.y = y
        self.z = z
    def zeroes():
        return Vector3D(0,0,0)
    def ones():
        return Vector3D(1,1,1)
    def __add__(self, other):
        return Vector3D(self.x+other.x,
                        self.y+other.y,
                        self.z+other.z)
    def __str__(self):
        return "({}, {}, {})".format(self.x, self.y, self.z)
    def length(self):
        return math.sqrt(self.x**2+self.y**2+self.z**2)
```

Answers

```
import math
class Vector3D:
    def __init__(self, x, y, z):
        self.x = x
        self.y = y
        self.z = z
    def zeroes():
        return Vector3D(0,0,0)
    def ones():
        return Vector3D(1,1,1)
    def __add__(self, other):
        return Vector3D(self.x+other.x,
                        self.y+other.y,
                        self.z+other.z)
    def __str__(self):
        return "({}, {}, {})".format(self.x, self.y, self.z)
    def length(self):
        return math.sqrt(self.x**2+self.y**2+self.z**2)
```

Class Method, even though it generates an object

Answers

```
import math
class Vector3D:
    def __init__(self, x, y, z):
        self.x = x
        self.y = y
        self.z = z
    def zeroes():
        return Vector3D(0,0,0)
    def ones():
        return Vector3D(1,1,1)
    def __add__(self, other):
        return Vector3D(self.x+other.x,
                        self.y+other.y,
                        self.z+other.z)
    def __str__(self):
        return "({}, {}, {})".format(self.x, self.y, self.z)
    def length(self):
        return math.sqrt(self.x**2+self.y**2+self.z**2)
```

Class Method, even though it generates an object

Answers

```
import math
class Vector3D:
    def __init__(self, x, y, z):
        self.x = x
        self.y = y
        self.z = z
    def zeroes():
        return Vector3D(0,0,0)
    def ones():
        return Vector3D(1,1,1)
    def __add__(self, other):
        return Vector3D(self.x+other.x,
                        self.y+other.y,
                        self.z+other.z)
    def __str__(self):
        return "({}, {}, {})".format(self.x, self.y, self.z)
    def length(self):
        return math.sqrt(self.x**2+self.y**2+self.z**2)
```

Instance method

Answers

```
import math
class Vector3D:
    def __init__(self, x, y, z):
        self.x = x
        self.y = y
        self.z = z
    def zeroes():
        return Vector3D(0,0,0)
    def ones():
        return Vector3D(1,1,1)
    def __add__(self, other):
        return Vector3D(self.x+other.x,
                        self.y+other.y,
                        self.z+other.z)
    def __str__(self):
        return "({}, {}, {})".format(self.x, self.y, self.z)
    def length(self):
        return math.sqrt(self.x**2+self.y**2+self.z**2)
```

Dunder instance method

Answers

```
import math
class Vector3D:
    def __init__(self, x, y, z):
        self.x = x
        self.y = y
        self.z = z
    def zeroes():
        return Vector3D(0,0,0)
    def ones():
        return Vector3D(1,1,1)
    def __add__(self, other):
        return Vector3D(self.x+other.x,
                        self.y+other.y,
                        self.z+other.z)
    def __str__(self):
        return "({}, {}, {})".format(self.x, self.y, self.z)
    def length(self):
        return math.sqrt(self.x**2+self.y**2+self.z**2)
```

Instance method

Dunder Methods

- Python reserves special names for functions that allows the programmer to emulate the behavior of built-in types
    - For example, we can create number like objects that allow for operations such as addition and multiplication
        - These methods have special names that start out with two underscores and end with two underscores

- Aside: If you preface a variable / function / class with a single underscore, you indicate that it should be treated as reserved and not used outside of the module / class

Dunder Method

- A class for playing cards:
  - A card has a suit and a rank
    - We define this in the constructor __init__

```
class Card:
    def __init__(self, suit, rank):
        self.suit = suit
        self.rank = rank
```

Dunder Method

- We want to print it
  - Python likes to have two methods:
    - __repr__ for more information, e.g. errors
    - __str__ for the print-function
  - Both return a string

```
class Card:

    def __str__(self):
        return self.suit[0:2]+self.rank[0:2]
    def __repr__(self):
        return "{}-{}".format(self.suit, self.rank)
```

Dunder Method

- __repr__ is used when we create an object in the terminal

```
>>> Card("Heart", "Queen")
Heart-Queen
```

- __str__ is used within print or when we say `str(card)`

```
>>> print(Card("Heart", "Queen"))
HeQu
>>> str(Card("Heart", "Queen"))
'HeQu'
```

Dunder Method

- We now create a carddeck class
  - Consists of a set of cards
  - Constructor uses a list of ranks and a list of suits

```
class Deck:
    def __init__(self, los, lov):
        self.cards = [Card(suit, rank) for suit in los
                                       for rank in lov]
```

Dunder Method

- We create the string method. Remember that it needs to return a string.

```
class Deck:
    def __init__(self, los, lov):
        self.cards = [Card(suit, rank) for suit in los
                                       for rank in lov]
    def __str__(self):
        result = []
        for card in self.cards:
            result.append(str(card))
        return " ".join(result)
```

Dunder Method

- In order to allow python to check whether a deck exists, we want to have a length class. Besides, it is useful in itself.
  - `if deck:` works by checking `len(deck)`

```
class Deck:

    def __len__(self):
        return len(self.cards)
```

Dunder Method

- Given a deck, we want to be able to access the i-th element.
- We do so by defining __getitem

```
class Deck:

    def __getitem__(self, position):
        return self.cards[position]
```

Dunder Method

- This turns out to be very powerful:

```
french_deck = Deck(['Spade', 'Diamonds', 'Hearts', 'Clubs'],
                   ['Ace', 'King', 'Queen', 'Jack', '10', '9',
                    '8', '7', '6', '5', '4', '3', '2'])
```

- We can print out the i-th element of the deck

```
>>> str(french_deck[5])
'Sp9'
```

- But we can also **slice** the deck

```
>>> print(french_deck[6:12])
[Spade-8, Spade-7, Spade-6, Spade-5, Spade-4, Spade-3]
```

Dunder Method

- We can use random.choice() to select a card

```
>>> random.choice(french_deck)
Diamonds-9
```

- Only for random.sample do we need to go to the underlying instance field

```
>>> random.sample(french_deck.cards, 5)
[Hearts-8, Hearts-2, Hearts-Ace, Hearts-6, Diamonds-Ace]
>>> random.sample(french_deck.cards, 5)
[Hearts-5, Clubs-Queen, Diamonds-Ace, Clubs-3, Clubs-King]
```

  - But this is ugly and we better write a class method for it.