CS303E: Elements of Computers and Programming

Objects and Classes

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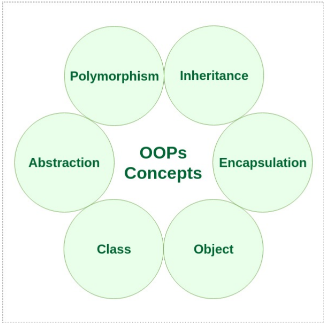
Python and OO

Python is an *object-oriented* (OO) language. That implies a certain approach to thinking about problems.

Basic idea: conceptualize any problem in terms of a collection of "objects"—data structures consisting of data fields and methods together with their interactions.

Programming techniques may include: data abstraction, encapsulation, messaging, modularity, polymorphism, and inheritance. *We'll talk about some of these later.*



Object Orientation

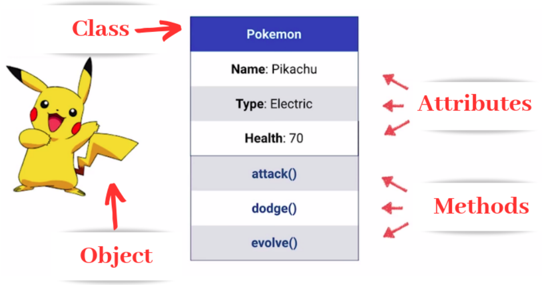
The basic idea of object oriented programming (OOP) is to view your problem as a *collection of objects*, each of which has certain state and can perform certain actions.

Each object has:

- some *data* (attributes) that it maintains characterizing its current state;
- a set of actions (*methods*) that it can perform (or you can perform on it).

Object Orientation

A user interacts with an object by calling its methods; this is called *method invocation*. That should be the *only way* that a user interacts with an object.



Significant object-oriented languages include Python, Java, C++, C#, Perl, JavaScript, Objective C, and others.

OO Paradigm: An Example

Example: A soda machine has:

- Attributes: products inside, change available, amount previously deposited, etc.
- Methods: accept a coin, select a product, dispense a soda, provide change after purchase, return money deposited, load products, etc.

Object Orientation

The programmer interacts with objects by invoking their methods, which may:

- update the state of the object,
- ask the object about its current state,
- compute some function of the state and externally provided values,
- some combination of these.

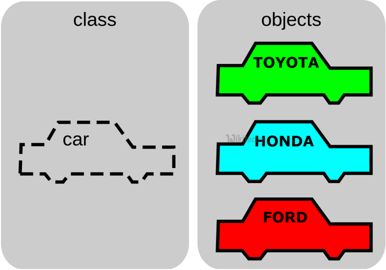
Name potential instances of each of these for our Soda Machine example.

Class vs. Instance of the Class

In Python, you implement a particular type of object (soda machine, calculator, etc.) with a `class`.

The class defines a "type" of object.

You can then create multiple objects (instances of the class).



A class is (sort of) like architectural drawing. It tells you how to construct the building.

An object (instance of the class) is the building created from the architect's plan.

Imagine that you're trying to do some simple arithmetic. You need a Calculator application, programmed in an OO manner. It will have:

Attributes: the current value of its *accumulator* (the value stored and displayed on the screen).

Methods: things that you can ask it to do: add a number to the accumulator, subtract a number, multiply by a number, divide by a number, zero out the accumulator value, etc.

Classes are like Types

Let's define a class for our simple interactive calculator.

Attribute: the current value of the accumulator.

Methods: all of the following.

- clear: zero the accumulator
- print: display the accumulator value
- add k: add k to the accumulator
- sub k: subtract k from the accumulator
- mult k: multiply accumulator by k
- div k: divide accumulator by k

A Calculator Class

Below is a (partial) Python implementation of the Calculator class:

In file `Calc.py`:

```
class Calc:
    """This is a simple calculator class. It stores and
    displays a single number in the accumulator.  To that
    number, you can add, subtract, multiply or divide."""

    def __init__(self):
        """Constructor for new Calc objects,
           with display 0."""
        self.accumulator = 0

    def __str__(self):
        """Allows print to display accumulator value
           in a nice string format."""
        return "Displaying: " + str(self.accumulator)

    def getAccumulator(self):
        return self.accumulator
```

Definition of class `Calc` continues on the next slide.

A Calculator Class

Continuation of the `Calc` class:

```
    def clear(self):
        self.accumulator = 0

    def add(self, num):
        self.accumulator += num

    def sub(self, num):
        ...

    def mult(self, num):
        ...

    def div(self, num):
        ...
```

Using Our Class

```
>>> from Calc import *    # import from Calc.py
>>> c = Calc()            # create a calculator object
>>> print( c )            # show its current value
Displaying: 0
>>> c.add( 10 )           # add 10
>>> print( c )
Displaying: 10
>>> c.div( 0 )            # try to divide by 0
Error: division by 0 not allowed.
>>> c.div( 2 )            # divide by 2
>>> print( c )
Displaying: 5.0
>>> c.mult( 4 )           # multiply by 4
>>> print( c )
Displaying: 20.0
>>> c.clear()             # clear the state
>>> print( c )
Displaying: 0
```

Note that it might have been better to have each operation print the accumulator value. What would you change?

Let's Take a Break

Defining Classes

General Form:

```
class ClassName:
    initializer
    methods
```

This defines a new class (type), which you can *instantiate* to create as many objects (instances) as you like.

The class *initializer* is a special function with name `__init__`. When called it supplies values to the class attributes.

The other methods are functions within the class that allow the world to interact with objects of the class.

The Circle Class

In file `Circle.py`:

```
import math

class Circle:
    def __init__(self, rad = 1):
        """ Construct a Circle object with radius
            rad (defaults to 1). """
        self.radius = rad

    def getRadius(self):          # getter
        return self.radius

    def setRadius(self, rad):     # setter
        self.radius = rad

    def getPerimeter(self):
        return 2 * math.pi * self.radius

    def getArea(self):
        return math.pi * ( self.radius ** 2 )
```

Using the Circle Class

```
>>> from Circle import *
>>> c1 = Circle()              # create a new Circle, radius 1
>>> c1.getRadius()
1
>>> c1.setRadius(5)            # reset c1's radius to 5
>>> c1.getRadius()
5
>>> c1.getArea()               # compute its area
78.53981633974483
>>> c1.getPerimeter()          # compute its perimeter
31.41592653589793
>>> c2 = Circle(10)            # make a new Circle, radius 10
>>> c2.getArea()               # get its area
314.1592653589793
```

Creating a New Object

Use the class name to create a new object of that class.

```
class Circle:

    def __init__(self, rad = 1):
        """ Construct a Circle object with radius
            rad (defaults to 1). """
        self.radius = rad

  ...
```

```
>>> c1 = Circle()
>>> c2 = Circle( 5 )
```

The function `__init__` is automatically called to initialize the object and define its attributes (also called its *data members*).

Creating a New Object

```
class Circle:
    def __init__(self, rad = 1):
        """ Construct a Circle object with radius
            rad (defaults to 1). """
        self.radius = rad

  ...
```

Notice that `__init__` has two parameters:

- self : refers to the object just created. It is used within the class definition, but not outside it.
- rad : it wouldn't make any sense to define a circle without a radius. It's an attribute/data member of the class.

The Other Methods

```
    ...
    def getRadius(self):
        # Return the radius
        return self.radius

    def getPerimeter(self):
        # Compute the perimeter
        return 2 * math.pi * self.radius
    ...
```

The other methods can refer to the class attributes using the dot notation.

They have `self` as a parameter at definition. When they are called on a class instance (object), self is an *implicit parameter* referring to the object itself.

```
>>> c1.getRadius()                # self references c1
5
>>> c1.getPerimeter()
31.41592653589793
```

Accessing Attributes

It is (sometimes) possible to directly access the attributes of a class:

```
c1 = Circle()
>>> c1.radius          # bad practice
1
>>> c1.getRadius()     # better
1
```

But it's a bad idea, for two reasons:

1. Anyone can tamper with your class data, including setting it to illegal values.
2. The class becomes difficult to maintain. Suppose some user sets the Circle radius to a negative value.

Accessing Attributes

It's better to deny direct access to attributes; instead define *setters* (or mutators) and *getters* (or accessors).

```
    def getRadius(self):              # getter
        return self.radius

    def setRadius(self, radius):      # setter
        self.radius = radius
```

Even with setters and getters, there's nothing to prevent code from accessing attributes directly, unless you make the attribute *private*.

An attribute beginning with two underscores is private to the class.

The Circle Class with Private Attributes

```
import math

class Circle:
    # Construct a circle object, with radius
    # a private attribute.
    def __init__(self, rad = 1):
        self.__radius = rad

    def getRadius(self):
        return self.__radius

    def setRadius(self, rad):
        self.__radius = rad

    def getPerimeter(self):
        return 2 * math.pi * self.__radius

    def getArea(self):
        return math.pi * ( self.__radius ** 2 )
```

The only access to `__radius` outside the class is via the getter and setter methods.

Code Defensively: Reconsider Circle Setter

Notice that with this setter, there's nothing to prevent a malicious or careless user from setting the radius to an illegal value:

```
    def setRadius(self, radius):
        self.__radius = radius
```

This would be better:

```
    def setRadius(self, radius):
        if radius > 0:
            self.__radius = radius
        else:
            # leave radius unchanged and
               print
            # an error message
            print("Radius must be positive.")
```

Private Attributes

```
>>> from Circle import *
>>> c = Circle( 10 )
>>> c.getRadius()
10
>>> c.__radius          # violates privacy
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
AttributeError: 'Circle' object has no
   attribute '__radius'
>>> print( c )          # didn't define __str__
<Circle.Circle object at 0x7ff32a47e470>
```

Let's Take a Break

Everything's an Object

In Python, everything is an object, even numbers and strings. Every object has a unique id, accessed with the function `id()`.

You can access the class of any object with the function `type()`.

```
>>> from Circle import *
>>> c1 = Circle()
>>> type(c1)
<class 'Circle.Circle'>
>>> id(c1)
140162312889400
>>> type(7)
<class 'int'>
>>> id(7)
10914688
>>> type("xyz")
<class 'str'>
>>> id("xyz")
140162312889488
>>> id(4 + 1)
10914624
>>> id(5)
10914624
```

Printing a Class

If you want to print a class instance, you need to tell Python how to print it. Do that by defining a class method `__str__` that returns a `str`.

```
class Rectangle:
    def __init__(self, width = 2, height = 1):
         self.__width = width
         self.__height = height

    def __str__(self):
        return "Rectangle with width " + str(self.__width) + \
               " and height " + str(self.__height)
```

```
>>> from Rectangle import *
>>> r1 = Rectangle()
>>> print( r1 )
Rectangle with width 2 and height 1
>>> r2 = Rectangle( 3, 5 )
>>> print( r2 )
Rectangle with width 3 and height 5
```

`print` knows to call the `__str__` function on each argument.

Mutable vs. Immutable

Remember that integers and strings are *immutable* meaning that you can't change them.

Classes you define are mutable. For an immutable object, there is only one copy, which is why you can't change it.

```
>>> from Circle import *
>>> x = 7
>>> id(x)
10914688
>>> y = 7
>>> id(y)
10914688
>>> c1 = Circle()
>>> c2 = Circle()
>>> id(c1)
140497298719856
>>> id(c2)
140497298720920
>>> x is y              # are x, y the same object
True
>>> c1 is c2            # are c1, c2 the same object
False
```

Putting It All Together

Suppose you want to write a Python program to play Poker. What is the *object oriented* way of thinking about this problem?

First question: What are the *objects* involved in a game of Poker?

Putting It All Together

Suppose you want to write a Python program to play Poker. What is the *object oriented* way of thinking about this problem?

First question: What are the *objects* involved in a game of Poker?

- Card (rank and suit)
- Deck of Cards (an ordered collection of cards)
- Hand (a collection of 5 cards dealt from a Deck)
- Player (an entity that makes decisions about its hand)
- Table (several Players competing against each other)

There are probably other ways to conceptualize this problem. It's good practice to put each class into its own file.

Designing a Class: Card

Let's start at the bottom. Suppose we want to design a representation in Python of a playing Card.

- What data is associated with a Card?
- What actions are associated with a Card?

Designing a Class: Card

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- What data is associated with a Card?
- What actions are associated with a Card?

Data:

- Rank: "Ace", "2", "3", "4", "5", "6", "7", "8", "9", "10", "Jack", "Queen", "King"
- Suit: 'Spades', 'Diamonds', 'Hearts', 'Clubs'

Methods:

- Tell me your rank.
- Tell me your suit.
- How would you like to be printed?

Designing a Class

We'll define a `Card` class with those attributes and methods.

Notice that there are:

- a *class* definition (defines the type of an arbitrary playing card),
- *instances* of that class (particular cards).

Ranks and Suits

In the file Card.py

```
SUITS_NUMBER = 4
RANKS_NUMBER = 13

def isRank( r ):
    # Recognizer for a legal rank:
    return r == 'Ace' or r == '2' or r == '3' or r == '4' \
        or r == '5' or r == '6' or r == '7' or r == '8' \
        or r == '9' or r == '10' or r == 'Jack' \
        or r == 'Queen' or r == 'King'

def isSuit( s ):
    # Recognizer for a legal suit
    return s == 'Spades' or s == 'Diamonds' \
        or s == 'Hearts' or s == 'Clubs'
```

Notice that I chose to define these as *auxiliary* functions, defined outside of any class definition, but maybe used within one or more classes.

In the file Card.py

```
# We want to be able to convert from rank to number and vice
    versa.
def cardRankToIndex ( rank ):
    if rank == 'Ace': return 0
    elif rank == '2': return 1
      ...
    elif rank == 'King': return 12
    else:
        print( "Rank ", rank, "is not recognized" )

def cardIndexToRank ( i ):
    if i == 0: return 'Ace'
    elif i == 1: return '2'
      ...
    elif i == 12: return 'King'
    else:
        print( "Not legal index for rank:", i )
```

Write very similar code for Suits.

Card Class

In file/module Card.py

```
class Card:
    """A card object with a suit and rank."""
    def __init__(self, rank, suit):
        """Create a Card object with the given rank
        and suit."""
        if ( not isRank(rank) or not isSuit(suit)):
            print ("Not a legal card specification.")
            return
        self.__rank = rank
        self.__suit = suit

    def getRank(self):
        return self.__rank

    def getSuit(self):
        return self.__suit
```

Remember, error messages should be printed, not returned.

Poker: Card Class

```
    # This is the continuation of the Card class.

    def __str__(self):
        """Return a string that is the print representation
        of this Card's value."""
        return self.__rank + ' of ' + self.__suit
```

This tells `print` what string to display if you ask to print a Card object.

Poker: Card Class

```
>>> from Card import *
>>> isRank( 'Jack' )
True
>>> isRank( 'Knave' )
False
>>> isSuit( 'Clubs' )
True
>>> c1 = Card('2', 'Spades')
>>> print(c1)
2 of Spades
>>> c1.getRank()
'2'
>>> c1.getSuit()
'Spades'
>>> c1
<Card.Card object at 0x7fc56e59d780>
>>> c2 = Card('Queen', 'Hearts')
>>> print(c2)
Queen of Hearts
>>> (c1 < c2)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: unorderable types: Card() < Card()
```

Something Cool

We can't compare Card objects, unless we define what "less than" means for Cards.

We could add the following method to our `Card` class:

```
    def __lt__(self, other):
        return (   cardRankToIndex( self.__rank )   \
                 < cardRankToIndex( other.getRank() ))
```

This assumes that `other` is another Card object; if we're being very careful, we could check that in our code.

Note that this only compares the ranks; it doesn't even look at the suit.

Something Cool

Now we can compare two cards using a convenient notation:

```
>>> from Card import *
>>> c1 = Card('2', 'Spades')
>>> c2 = Card('5', 'Diamonds')
>>> c1 < c2
True
>>> c2 < c1
False
>>> c1 > c2
False
```

Notice that we're comparing cards only according to rank, and Ace is less than 2. Think how you'd define a more robust test.

Comparing Class Instances

You can use all of the standard relational operators assuming you have defined `__lt__` and `__le__` so Python can figure out what you mean. You can always do equality comparison $X == Y$, which will be the same as "is" (same object in memory) unless you define `__eq__`.

You can also define `__gt__` and `__ge__` but be careful that your definitions form a consistent collection.

You *shouldn't* define all of those functions, just enough to get it to work. That is, if you have `__lt__`, you don't need `__ge__` because that's just the negation.

Aside: Equality Comparisons

`(X == Y)` tests for structural equivalence of values. `(X is Y)` tests whether two objects are in fact the same object. Sometimes those are not the same thing

```
>>> x = [1, 2, 3]
>>> y = x
>>> z = [1, 2, 3]
>>> x == y
True
>>> x is y
True
>>> x == z
True
>>> x is z
False
```

Abstraction

Notice that we defined the Card class abstractly. There's nothing about it that indicates we're going to be playing Poker. *That's why it's good to start at the bottom!*

It would work as well for blackjack or canasta. It wouldn't work for Uno, Rook or another game using a specialty deck.

What would you do for such cases?

Now the *interface* to the Card class is the methods: getSuit(), getRank(), print, and the relational comparisons. *Any other way of manipulating a Card object "violates the abstraction."*

Aside: Those Funny Names

In general, any method name in Python of the form `__xyz__` is probably not intended to be called directly. These are called "magic methods" (or "dunder methods") and have associated functional syntax ("syntactic sugar"):

`__init__`	`ClassName()`
`__len__`	`len()`
`__str__`	`str()`
`__lt__`	`<`
`__eq__`	`==`
`__add__`	`+`

However, you often can call them directly if you want.

```
>> "abc".__add__("def")
'abcdef'
>> l = [1, 2, 3, 4, 5]
>>> len(l)
5
>>> l.__len__()
5
```

Next stop: More on Strings.