Introduction to Object Oriented Programming (in Python)

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Objectives

Today's objectives:

- Define key object-oriented (OO) concepts
- Use object-oriented approach to programming
- Instantiate an object
- Design and implement a basic class
- List key magic methods
- Use basic decorators
- Verify code using test driven development (TDD) and the Python debugger (PDB)

Agenda

Today's plan:

1. Introduction to OOP
2. Core OOP using Python
3. Advanced OOP using Python
4. Verification, unit tests, and debugging

References

A couple helpful references, arranged by increasing difficulty:

- Effective Python will help you raise your Python game
- Head First Design Patterns
- Design Patterns: Elements of Reusable Object-Oriented Software is the canonical reference
- Large-Scale C++ Software Design

Plus your favorite Python reference for language syntax. . .

Overview: goals of OOP

Object-Oriented Programming was developed to:

- Facilitate building large-scale software with many developers
- Promote software reuse:
  - Build software components (libraries) with reuse in mind
  - Improved code quality by using debugged components
- Decouple code, improving maintainability and stability of code
- Avoid mistakes, such as forgetting to initialize or deallocate a resource
- Improve productivity:
  - Through reuse
  - By promoting separation of concerns

Science and OOP

Often, OOP is not a good fit for doing science:

- Science is inherently linear:
  - Projects tend to build a pipeline
  - Most applications:
    1. Load data
    2. Compute something
    3. Serialize result to disk
  - Should be able to combine steps, similar to Unix's filters + pipes model
- But, need to know OOP:
  - To use libraries which have OO design
  - To build large-scale software

Using OOP

OOP requires changing how you think about code:

- As a library consumer:
  - Identify the classes with the functionality you need
  - Compose objects until you have the object you need to provide the service
- Objects provide a service to clients if they satisfy the interface's contract
- Class describes behavior and attributes of a type of object

Class vs. object/instance

A *class*:

- Defines a *user-defined type*, i.e., a concept with data and actions
- A full class type, on par with `float`, `str`, etc.
- Consists of:
  - Attributes (data fields)
  - Methods (operations you can perform on the object)

An *object*:

- Is an instance of a class
- Can create multiple instances of the same class

Attributes

An *attribute* is a property of a class

- Usually a variable
- Could look like a variable, but really be a getter/setter method
    - Decorate a function with the attribute's name with `@property`
    - Decorate the setter with `@<my_attribute>.setter`

Example: sci-kit learn

All regression models – `LinearRegression`, `LogisticRegression`, `Lasso`, `Ridge`, etc. – support the same interface:

Method	Action
`.fit(X, y)`	Train a model
`.predict(X)`	Predict target/label for new data
`.score(X, y)`	Compute accuracy given data and true labels

Huge benefits for user:

- Just instantiate the model you want
- Use same interface for every model!
- Minimizes cognitive load

The big three

OO revolves around three key concepts:

- Encapsulation
- Inheritance
- Polymorphism

Don't worry about templates and generics:

- Not related to OO
- But, often used with OO, especially with C++/Java

Encapsulation

Encapsulation forces code to manipulate an object's internal state only through method calls:

- You should always program this way, regardless of language:
  - Write a library to manage a resource
  - Only access the resource via the library
  - This is basic 'defensive programming'
  - Then, problems occur from using the library incorrectly or an error in the library
- **Python will not enforce encapsulation**:
  - Malicious code can directly access an object's data
  - Violating encapsulation, makes code impossible to maintain
  - *'We are all consenting adults'*

Public vs. protected vs. private

Some languages (C++, Java) enforce encapsulation by making attributes public, protected, or private:

- *Public*: accessible by any external code, e.g., a public interface
- *Protected*: access depends on the language, typically inaccessible by external code and accessible by derived classes
- *Private*: accessible only by code from the same class, but not derived classes
- In Python, start the name with _ if it is private

Inheritance

Derive a *child* class from a *base* class:

- Base class defines general behavior
- Child class specializes behavior
  - Child gets all the functionality of Base class for free
  - Child methods override Base methods of the same name

Example: Inheritance

```python
class Metric(object):
    '''General model of a Metric'''
    def score(self, y_true, y_hat):
        pass

class RMSE(Metric):
    '''RMSE Metric'''
    def score(self, y_true, y_hat):
        pass

class MAPE(Metric):
    '''MAPE Metric'''
    def score(self, y_true, y_hat):
        pass
```

Polymorphism

OO code enables polymorphism:

- Treat multiple objects the same if they support same interface
- Usually, objects must instantiate classes with a common base class
- Python uses *duck-typing*:
  - *'If it looks like a duck and quacks like a duck, it is a duck'*
  - Python does not require that classes are related via inheritance
  - Polymorphism works if object instantiates a class which defines the necessary attribute or method

More on duck-typing

Many languages – think C++, Java, and FORTRAN – use *strong typing* and require that classes use inheritance to support polymorphism:

- Python is *weakly typed*: types are determined on the fly based on usage
- A class does not need to inherit the interface:
  - Classes only need to support the interface
  - Inheritance makes it easier to ensure that the interface is supported, e.g., via an *Abstract Base Class* (ABC)
  - A class may only support part of an interface
- At run-time, Python will check if an object has the desired method or attribute
  - If the method is missing, Python will raise an `AttributeError`

Very basic OOP design

Decompose your problem into nouns and verbs:

- Noun $\Rightarrow$ implement as a class
- Verb $\Rightarrow$ implement as a method

Basic OO design

Build classes via:

- Composition/aggregation:
  - Class contains an object of a class with the desired functionality
  - Often, just basic types: `str`, `float`, `list`, `dict`, etc.
  - *HasA* $\Rightarrow$ use aggregation
- Inheritance
  - Class specializes behavior of a base class
  - *IsA* $\Rightarrow$ use inheritance
  - In some cases, derived class uses a *mix-in* base class only to provide functionality, not polymorphism

An interface is a contract

An interface is a contract between the client and the service provider:

- Isolates client from details of implementation
- Client must satisfy preconditions to call method/function
- Respect boundary of interface:
  - Library/module provides a service
  - Clients only access resource/service via library
  - Then bugs arise from arise from incorrect access or defect in library

Testing an interface

Make sure your interface is intuitive and friction-free:

- Use unit test or specification test
  - To verify interface is good before implementation
  - To exercise individual functions or objects before application is complete
  - Framework can setup and tear-down necessary test fixture
- Stub out methods using `pass`
- Test Driven Development (TDD):
  - Red/Green/Green
  - Write unit tests
  - Verify that they fail
  - Implement code
  - Refactor code
- Does interface make sense?

Example of first version of a class

```
class FancyRegression(object):
    def __init__(self):
        pass

    def fit(self, X, y):
        pass
```

Separation of concerns (SoC)

Try to keep 'concerns' separate:

- Use different layers for each concern
- A *concern* is a set of information or a resource that affects the program
- Keep layers distinct, i.e., write modular code
- Think Unix:
  - Each layer does one thing and does it well
  - Easy to combine
- Avoid cyclic dependencies
- SoC is crucial when building distributed applications

Core OOP using Python

Getting Started

Define classes to embody concepts:

- Use `class` keyword
- Always derive your class from object:
- Capitalize name of each class

```
class FancyRegression(object):
    pass
```

How to define a class

```python
class FancyRegression(object):
    '''Profound doc goes here!
    Remark: Capitalize class name
    Remark: Always inherit from 'object'
    '''
    def __init__(self, sharpness=1.0, shininess=0.0):
        '''Setup necessary resources.'''
        self.sharpness = sharpness
        self.shininess = shininess

    def fit(self, X, y):
        '''Train model using XYZ method.'''
        pass
```

`self`

Use `self` to refer to an instance's own, unique data:

- I.e., use `self` for 'self-reference'
- Use `self` in a class's member functions to access instance-specific data
- Like `this` in C++
- Start each member function's argument list with `self`
    - ... unless it is a static or class member function

Inheritance

To inherit from a base class, specify the parent classes instead of `object` when you define the class:

```
class FancyRegression(Regression):
    ...
```

- Can call all of parent's methods on child
- But, child can override methods from parent to specialize behavior
- Can check if an object is a specific class via `isinstance()`

def __init__(self, ...):

Define the special method `__init__` to initialize each instance of a class:

- Handles instance-specific initialization
- Called whenever an instance of the class is created
- Use `self` to refer to the instance's member data and functions
- No need to worry about cleanup because of garbage collection, unlike other languages

If a class inherits from another, the derived class must call the base class's constructor:

- Use `super(MyClass, self).__init__()` to call base class's `__init__()`
- Always initialize base class before derived class

Example: def __init__(self, ...):

```
class FancyRegression(Regression):
    def __init__(self, sharpness=1.0, shininess=0.0):
        '''Setup necessary resources.'''
        super(FancyRegression, self).__init__()
        self.sharpness = sharpness
        self.shininess = shininess
```

Public vs. private

In Python, you cannot enforce that a method is private:

- Start name with _ to indicate that a function, method, or class is private
- But, ‘we are all consenting adults’ so deviants can still access private resources

Advanced OOP using Python

Key advanced OOP features in Python

Key features:

- `*args` and `**kwargs`
- Class data and static methods
- Magic methods
- Callables
- Context manager
- Decorators
- ABCs
- Some popular patterns

*args and **kwargs

Shorthand to refer to a variable number of arguments:

- For regular arguments, use `*args`:
  - `*args` is a `list`
  - `def genius_func(*args):` to define a function which takes multiple arguments
  - Can also call function using a `list`, if you dereference

```
my_list = list(...)
genius_func(*my_list)
```

- For keyword arguments, use `**kwargs`:
  - `**kwargs` is a `dict`
  - `def genius_func(**kwargs):` to define a function which takes multiple keyword arguments
  - Can also call function using a `dict`, if you dereference

```
my_dict = {'a': 15, 'b': -92}
genius_func(**my_dict)
```

Example

- Case 1: supply all args via a list

```
def myargs(arg1, arg2, arg3):
    return arg1 * arg2 + arg3

>> z = [ 2, 3, 4 ]
>> myargs(*z)
10
```

- Case 2: process variable number of arguments

```
def args2list(*args):
    return [ ix for ix in args]

>> args2list(1, 2, 3, 4)
[1, 2, 3, 4]
```

Class methods and data

Can have class-specific data:

- Example: number of instances of class which have been created
- Decorate member function with `@classmethod`
- Use `cls` instead of `self` to refer class data
- ... except in a method which already refers to instance data

Example

```
class ObjCounter(object):
    obj_list = []
    def __init__(self):
        super(ObjCounter, self).__init__()
        self.obj_list.append(self)

    @classmethod
    def n_created(cls):
        return len(cls.obj_list)

In [14]: oc1 = ObjCounter()

In [15]: oc2 = ObjCounter()

In [16]: ObjCounter.n_created()
Out[16]: 2
```

Static methods and data

Static methods are normal functions which live in a class's namespace:

- Do not access class or instance data
- No `self` or `cls` argument
- Just access by prepending name with the class's name:

```
class StaticExample(object):
    @staticmethod
    def call_me():
        print 'Feed me, Seymour!'

In [18]: StaticExample.call_me()
Feed me, Seymour!
```

Magic methods (1/2)

Add support to your class for *magic methods*:

- To support iteration
- To support math and relational operators
- To make your class callable, like a function with state (i.e., a functor)
- To create a new container, e.g., support `len()`

See: magic methods

Magic methods (2/2)

Popular magic methods:

Method	Purpose
`__init__`	Constructor, i.e., initialize the class
`__str__`	Define behavior for `str(obj)`
`__repr__`	Define behavior for `repr(obj)`
`__len__`	Return number of elements in object
`__call__`	Call instance like a function
`__cmp__`	Compare two objects
`__iter__`	Returns an iterable (which supports `__iter__` and `next()`)

Plus methods for order relations ($==$, $!=$, $<$, $>$), attribute access, math, type conversion, custom containers, context managers, ...

Decorators

A *decorator* is a function which wraps another function:

- Looks like the original function, i.e., `help(myfunc)` works correctly
- But, decorator code runs before and after decorated function
- Lecture focuses on using existing decorators
- To write a custom decorator:
  - See Effective Python
  - Use `functools.wrap` to get correct behavior

Common decorators:

Some common decorators are:

- `@property` often with `@<NameOfYourProperty>.setter`
- `@classmethod` - can access class specific data
- `@staticmethod` - group functions under class namespace
- `@abstractmethod` - define a method in an ABC
- Can also find decorators for logging, argument checking, and more

Properties

Properties look like member data:

- Actually returned by a function which has been decorated with `@property`
- Cannot modify the field unless you also create a setter, by decorating with `@<field_name>.setter`
- Gives you flexibility to change implementation later

Example: @property

```python
class FancyRegression(object):
    def __init__(self, name)
        self._name = name

    @property
    def name(self):
        return self._name

    @name.setter
    def name(self, new_name):
        self._name = new_name
```

Example of different types of methods

From StackOverflow

```
class A(object):
    def foo(self,x):
        print "executing foo(%s,%s)" % (self,x)

    @classmethod
    def class_foo(cls,x):
        print "executing class_foo(%s,%s)" % (cls,x)

    @staticmethod
    def static_foo(x):
        print "executing static_foo(%s)" % x
```

Example: continued

```
In [20]: a = A()

In [21]: a.foo(1)
executing foo(<__main__.A object at 0x1083db5d0>,1)

In [22]: a.class_foo(2)
executing class_foo(<class '__main__.A'>,2)

In [23]: a.static_foo(3)
executing static_foo(3)
```

Design patterns

Many design patterns exist to standardize best practice:

- Worth learning if you regularly develop software
- See references
- Key patterns we will use:
  - Callable (Functor) for use with MapReduce
  - Resource Acquisition is Initialization (RAII)

Callable pattern

Class behaves like a function but can store state and other information

- Implement `__call__()`
- Acts like a Functor in C++, i.e., like a function which can store state
- Often used with MapReduce because serializable and more flexible than a lambda or free function

Example

Often, it is best practice to pass a *callable* to map or reduce:

```
class MyMapper(object):
    def __init__(state):
        self.state = state

    def __call__(elem):
        '''Perform map operation on an element'''
        return self._impl(elem)

    def _impl(elem)
        ...
```

ABCs

An *Abstract Base Class* (ABC):

- Defines a standard interface for derived objects
- Cannot be instantiated – to ‘access,’ must derive a class from the ABC
- May contain some implementation for methods

See doc on abc module for details

Verification, unit tests, and debugging

Verification and debugging

Verifying your code is correct, and finding and fixing bugs are critical skills:

- Just because your code runs, doesn't mean it is correct
- Write unit tests to exercise your code:
  - Ensures interfaces satisfy their contracts
  - Exercise key paths through code
  - Identify any bugs introduced by future changes which break existing code
  - Test code before implementing entire program
- When unit tests fail, use a debugger to examine how code executes
- Both are critical skills and will save you hours of time
- Verification and Validation in Scientific Computing discusses rigorous framework to ensure correctness

Unit tests and TDD

Unit tests exercise your code so you can test individual functions:

- Use a unit test framework – `unittest2` (best) or `nose`
- Unit tests should exercise key cases and verify interfaces
- A unit test can setup fixtures (i.e., resources) needed for testing
- *Test Driven Development* is a good approach to development:
  - *Red*: implement test and check it fails
  - *Green*: implement code and make sure it passes
  - *Green*: refactor and optimize implementation
- 'Only refactor in the presence of working tests'
- Save time by verifying interfaces and catching errors early
- Catch errors if a future change breaks things

Using PDB

When unit tests fail, use the debugger to find a bug:

- If working in ipython, will display line of code which caused exception
- For complex bugs, debug via PDB
- To start PDB, at a specific point in your code, add:

```
import pdb

...
pdb.set_trace()  # Start debugger here
...
```

- See PDB's `help` for details
- Learn how to use a debugger. It will save you a lot of pain...

Essential debugging

Once you have mastered one debugger, you have mastered them all:

Command	Action
`h`	help
`b`	set a break-point
`where`	show call stack
`s`	execute next line, stepping into functions
`n`	execute next line, step over functions
`c`	continue execution
`u`	move up one stack frame
`d`	move down one stack frame

code.interact() trick

In some environments (e.g., Cython), PDB may not work:

- Use `code.interact()` to start a Python interpreter with local context
- Exit by typing `^D`
- Better than printing. . .
- Need to `import` any libraries you want to use

```
...
import code
code.interact('Ring 5 of Inferno', local=locals())
...
```

Debugging tricks

Some hard-won debugging tips:

- When starting any project ask, 'How will I debug this?'
- Program defensively; write code which facilitates debugging
- If you cannot figure out what is wrong with your code, something you think is true most likely isn't
- Explain your problem to a rubber duck . . . or friend
- Try to produce the smallest, reproducible test case
- If it used to work, ask yourself, 'What changed?'
- Add logging, but beware of Heisenberg: when you measure a system, you perturb it . . .

Summary

- What is the difference between a class and an object?
- What are the three key components of OOP? How do they lead to better code?
- How should I implement my code if the relationship is *IsA*? What if the relationship is *HasA*?
- What is duck typing?
- What should you do ensure an object is initialized correctly?
- What are magic methods?
- What are the benefits of TDD? What does Red/Green/Green mean?