

# Introduction to Object Oriented Programming (in Python)

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October 20, 2015

# 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:

- ➊ Introduction to OOP
- ➋ Core OOP using Python
- ➌ Advanced OOP using Python
- ➍ 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

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



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
<code>.fit(X, y)</code>	Train a model
<code>.predict(X)</code>	Predict target/label for new data
<code>.score(X, y)</code>	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'*

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

```
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 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`



# 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

# Very basic OOP design

When designing in the OO style, decompose your problem into nouns and verbs:

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

# Basic OO design

Typically, 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

# 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

```
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
```

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
```

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 make your class iterable
- To make your class callable like a function with state (i.e., a functor)
- To make your class behave like a container, e.g., support `len()`

See: [magic methods](#)

# Magic methods (2/2)

Popular magic methods:

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

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



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

```
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)
        ...
```

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 in `__init__()`?
- What are magic methods?
- What are the benefits of TDD? What does Red/Green/Green mean?