Object-Oriented Programming

Scientific Programming with Python

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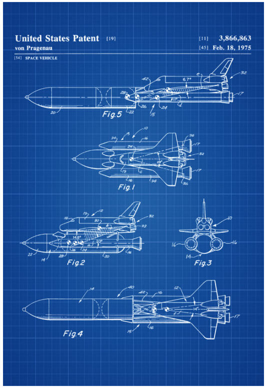
Outline

Setting the scene

Object-oriented programming is a **programming paradigm**.

- Imperative programming
  - **Object-oriented**
  - Procedural
- Declarative programming
  - Functional
  - Logic

What is Object-Oriented Programming?



Segment programs into instances of different object classes:

- **Instance variables** to describe the state of the object
- **Methods** to model the behaviour of the object

A **class** definition is like a **blueprint**. Programs create instances and execute their methods.

Why might OOP be a good idea?

DRY (Don't repeat yourself):

Create class functionality once, **use repeatedly** across programs.
Inheritance allows easy creation of new classes by extending existing ones.

KIS (Keep it simple):

Split functionality into **basic building blocks** and **algorithms invoking them**. This creates a natural code structure.

Complex problems require more than single instruction sequences for maintainable code.

Example of a class

```python
class Dog:
    def __init__(self, color="brown"):
        self.color = color

    def make_sound(self):
        print("Wuff!")

# create an instance 'snoopy' of the class Dog
snoopy = Dog()

# first argument (self) is this Dog instance
snoopy.make_sound()

# change snoopy's color
snoopy.color = "yellow"
```

- Start with `class` keyword.
- Methods: functions in class scope with `self` as first argument.
- `__init__`: called when creating new instances.
- Data attributes are defined in `__init__`.

Fundamental Principles of OOP (I)

Encapsulation

- Expose only **necessary parts** (public interface).
- Hide implementation details for abstraction.
- Break large problems into understandable parts.

In Python:

- No explicit private/public declarations.
- Convention: private parts start with _.
- Uses **documentation** and **conventions** instead of enforcement.

Example of Encapsulation

```python
class Dog:
    def __init__(self, color="brown"):
        self.color = color
        self._mood = 5

    def _change_mood(self, change):
        self._mood += change
        self.make_sound()

    def make_sound(self):
        if self._mood < 0:
            print("Grrrr!")
        else:
            print("Wuff!")

    def pat(self):
        self._change_mood(1)

    def beat(self):
        self._change_mood(-2)
```

- Use `pat` and `beat` methods to change mood.
- Don't access `_mood` or `_change_mood` directly.

Fundamental Principles of OOP (II)

Inheritance

- Create subclasses that **inherit/extend parent classes**.
- Override methods, add specialized behavior.

In Python:

- Inherit from one/multiple classes (multiple not recommended).
- Access parent methods via `super`.
- All classes derive from `object` (implicit).

Example of Inheritance

```python
class Mammal:
    def __init__(self, color="grey"):
        self.color = color
        self._mood = 5

    def _change_mood(self, change):
        self._mood += change
        self.make_sound()

    def make_sound(self):
        raise NotImplementedError

    def pat(self):
        self._change_mood(1)

    def beat(self):
        self._change_mood(-2)
```

```python
from mammal import Mammal

class Dog(Mammal):
    def __init__(self, color="brown"):
        super().__init__(color)

    def make_sound(self):
        if self._mood < 0:
            print("Grrrr!")
        else:
            print("Wuff!")
```

- `super().__init__(color)`: calls parent constructor.
- `super`: accesses parent class methods.
- Used when extending parent methods.

Fundamental Principles of OOP (III)

Polymorphism

- **Treat subclasses like parent class**, execute specialized behavior.
- *Example:* All mammals make sounds; dogs bark.

In Python:

- Python is a **dynamically typed language**: the type (class) of a variable is only known when the code runs.
- **Duck Typing:** No need to know class of object if it provides the required methods: "If it looks like a duck, swims like a duck, and quacks like a duck, then it probably `is` a duck." (and we treat it as a duck)
- Type checking can be performed via the `isinstance` function, but generally prefer duck typing and polymorphism.

Example of Polymorphism

```python
from animals import Dog, Cat, Bear

def caress(mammal, number_of_pats):
    if isinstance(mammal, Bear):
        raise TypeError("Bad Idea!")
    for _ in range(number_of_pats):
        mammal.pat()

d, c, b = Dog(), Cat(), Bear()
caress(d, 3) # "Wuff!" (3x)
caress(c, 3) # "Purr!" (3x)
caress(b, 3) # raises TypeError
```

- `caress` works for all objects having a method `pat`
- Special behaviour for bears:
  use `isinstance(mammal, Bear)` to check if `mammal` is a bear.
- Dynamic typing makes function overloading like in other languages impossible!

Python Specialities – Magic Methods

```python
class Dog:
    def __init__(self, name, color="brown"):
        self.name = name
        self.color = color
        self._mood = 5

    def __repr__(self):
        return f"{self.name}: {self.color} dog"

snowy = Dog("snowy", "white")
print(snowy) # snowy: white dog
```

- Magic methods (full list here) start and end with two underscores ("dunder").
- They customise standard Python behavior (*e.g.* string representation or operator definition).

Python Specialities – Property

```python
class Dog:
    def __init__(self, color="brown"):
        self.color = color
        self._mood = 5

    def _get_mood(self):
        if self._mood < 0:
            return "angry"
        else:
            return "happy"

    mood = property(_get_mood)

# create an instance 'snowy' of the class Dog
snowy = Dog("white")
print("Snowy is", snowy.mood)
```

- `property()` has upto four arguments:
  1. Getter
  2. Setter
  3. Deleter
  4. Documentation string
- Access calculated values like data attributes.
- Create read-only attributes.
- Preprocess assigned values (see later).

Python Specialities – Property

```
class Dog:
    def __init__(self, color="brown"):
        self.color = color
        self._mood = 5

    @property
    def mood(self):
        if self._mood < 0:
            return "angry"
        else:
            return "happy"

# create an instance 'snowy' of the class Dog
snowy = Dog("white")
print("Snowy is", snowy.mood)
```

- `property()` has upto four arguments:
    1. Getter
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- Create read-only attributes.
- Preprocess assigned values (see later).

Python Specialities – Classmethods

```python
class Dog:
    def __init__(self, name, color="brown"):
        self.name = name
        self.color = color

    @classmethod
    def from_string(cls, s):
        name, *color = s.split(",")
        if not color or type(color) != str:
            return cls(name)
        return cls(name, color)

snowy = Dog.from_string("snowy,white")
```

- A `classmethod` takes as its first argument a class instead of an instance of the class. It is therefore called `cls` instead of `self`.
- One usecase is to write multiple constructors for a class, e.g.:
  - Default `__init__`.
  - From serialized string.
  - From database/file.
- Other usecases
  - Keep track/update existing objects (changes class variable).
  - Instance-independent methods
  - . . .

Python Specialities – Class attributes

```python
class Dog:
    breed = "dog"
    all_ = set()

    def __init__(self, name, color="brown"):
        self.name = name
        self.color = color
        Dog.all_.add(self)

    def __repr__(self):
        return f"{self.name}: {self.color} {self.breed}"

Dog("snowy", "white")
balto = Dog("balto")
balto.breed = "husky"
print(Dog.all_) # {snowy: white dog, balto: brown husky}
```

- A class can also have attributes that are shared among all its objects.
- If the attribute is modified, all objects will see this ("class global").
- **Pitfall assignment:** Assigning to an instance (`balto.breed = "husky"`), creates a new instance attribute, hiding the class one. You need the class to modify the class attribute (`type(balto).breed = "canis"`)

Advanced OOP Techniques

There are many advanced techniques that we didn't cover:

- Multiple inheritance: Deriving from multiple classes; it can create a real mess. Need to understand the Method Resolution Order (MRO) to understand `super`.
- Monkey patching: Modify classes and objects at runtime, *e.g.* overwrite or add methods.
- Abstract Base Classes: Enforce that derived classes implement particular methods from the base class.
- Metaclasses: (derived from type), their instances are classes.

- Great way to overcomplicate when feeling clever.
- Avoid these - you'll likely regret it (KIS).

Science Examples – Vector

```python
class Vector3D:
    def __init__(self, x, y, z):
        self.x, self.y, self.z = x, y, z

    def __add__(self, other):
        return type(self)(self.x + other.x,
                          self.y + other.y,
                          self.z + other.z)

    @property
    def length(self):
        return (self.x**2+self.y**2
                +self.z**2)**0.5

    @length.setter
    def length(self, length):
        scale = length/self.length
        self.x *= scale; self.y *= scale; self.z *= scale

    # decorators could be replaced by `length = property(....)`
    # but functions would need distinguishable names
```

```python
from vector import Vector3D

v1 = Vector3D(0, 1, 2)
v2 = Vector3D(1,-3, 0)
v3 = v1 + v2
print(v3.length) # 3.0
v3.length = 6
print(v3.x, v3.y, v3.z)
```

- Custom type with optimized behavior.
- Custom functionality.
- `type(self)` in `__add__`: simplifies inheritance.
- `@length.setter`: marks property setter.

Science Examples – Dataset

```python
import numpy as np

class Dataset:
    mandatory_metadata = ["label", "color", "marker"]
    def __init__(self, datafile, **metadata):
        for key in self.mandatory_metadata:
            if key not in metadata:
                raise KeyError("Missing metadata", key)
        self.metadata = metadata
        self.data = np.loadtxt(datafile, delimiter=",")
        self.validate()

    def validate(self):
        if self.data.shape != (4, 10):
            raise ValueError("Bad shape of data, has to be (4, 10).")

    @property
    def label(self):
        return self.metadata["label"]

    def peak_row(self):
        return self.data.max(axis=1).argmax()
```

```python
from dataset import Dataset

ds = Dataset("data_0.csv",
        label="calibration",
        color="r",
        marker="+")
print(ds.label)
```

- Store metadata with data.
- Data validation on load.
- Calculate derived quantities.

Science Examples – Sensors

```python
from urllib.request import urlopen

class Sensor:
    def __init__(self, offset=0, scale_factor=1):
        self.offset = offset
        self.scale = scale_factor

    def get_value(self):
        return (self._get_raw() + self.offset) * self.scale

    def _get_raw(self):
        raise NotImplementedError

class WebSensor(Sensor):
    def __init__(self, url, *args, **kwargs):
        super().__init__(*args, **kwargs)
        self._url = url

    def _get_raw(self):
        res = urlopen(self._url)
        return float(res.read())
```

```python
from sensors import WebSensor

sensor = WebSensor(
        "https://crbn.ch/sensor", 273
        )
print(sensor.get_value())
```

- Combine configuration with functionality.
- Support different sensor access methods.

Science Examples – Value with Uncertainty

```python
class UncertVal:
    def __init__(self, value, uncertainty=0):
        self.val = value
        self.std = uncertainty

    def __str__(self):
        return f"{self.val} +/- {self.std}"

    def add(self, other, corr=0):
        variance = (self.std ** 2 + other.std ** 2
                    + 2 * self.std * other.std * corr)
        return type(self)(self.val + other.val,
                          variance ** 0.5)

    def __add__(self, other):
        return self.add(other)
```

```python
from uncertval import UncertVal

a = UncertVal(2, 0.3)
b = UncertVal(3, 0.4)
print(a + b)  # 5 +/- 0.5
```

- Group related values.
- Useful string representation.
- Operators respect value relationships.

Object-Oriented Design Principles and Patterns

How to do Object-Oriented Design right:

- **Rule of three**: Third repetition $\rightarrow$ create class/function.
- Sketch with **pen and paper**.
- Be pragmatic, not perfectionist about real-world correspondence.
- **Testability**: good design criterion.

How design principles can help:

- Design principles tell you in an abstract way what a good design should look like (most come down to loose coupling).
- Design Patterns are concrete solutions for reoccurring problems.

Some Design Principles

Scope of classes:

- **One class = one single clearly defined responsibility.**
- **Favor composition over inheritance.**
  Inheritance is not primarily intended for code reuse, its main selling point is polymorphism. “Do I want to use these subclasses interchangeably?”
- Separate **varying aspects** from **stable ones**.
  Open for extension, closed for modification.

How to design (programming) interfaces:

- **Principle of least knowledge.**
  Each unit should have only limited knowledge about other units. Only talk to your immediate friends.
- Minimize the *surface area* of the interface.
- **Program to an interface**, not an implementation. Do not depend upon concrete classes.

Design Patterns

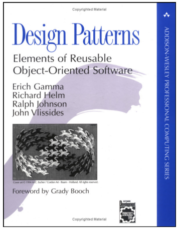
Purpose & background:

- Idea of concrete design approach for recurring problems.
- Closely related to the rise of the traditional OOP languages C++ and Java.
- More important for compiled languages (Open-Closed principle stricter!) and those with stronger enforcement of encapsulation.

Examples:

- **Decorator pattern**
- **Strategy pattern**
- Factory pattern
- . . .

Comprehensive list here.


Design Patterns
Elements of Reusable Object-Oriented Software
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Richard Helm
Ralph Johnson
John Vlissides
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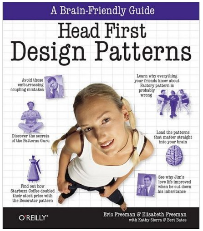
A Brain-Friendly Guide
Head First
Design Patterns
O'REILLY
Eric Freeman & Elisabeth Freeman
with Kathy Sierra & Bert Bates

Decorator Pattern

Decorator Pattern – Motivation

Challenge:

- How to modify the behaviour of an individual object . . .
- . . . and allowing for multiple modifications.

Example: Implement a range of products of a coffee house chain

But what about the beloved add-ons?

(Do not confuse the decorator pattern with function decorators!)

```python
class Beverage:
    # imagine some attributes like
    # temperature, amount left,...
    _name = "beverage"
    _cost = 0.00

    def __str__(self):
        return self._name

    @property
    def cost(self):
        return self._cost

class Coffee(Beverage):
    _name = "coffee"
    _cost = 3.00

class Tea(Beverage):
    _name = "tea"
    ...
```

Decorator Pattern – First try

Solution:

- Implementation via subclasses

Issue: Number of subclasses explodes to allow for multiple modifications (*e.g.* `CoffeeWithMilkAndSugar`).

```
class Coffee(Beverage):
    _name = "coffee"
    _cost = 3.00

class CoffeeWithMilk(Coffee):
    _name = "coffee with milk"
    _cost = 3.30

class CoffeeWithSugar(Coffee):
    _name = "coffee with sugar"
    ...
```

Decorator Pattern – Second try

Solution:

- Implementation with switches

Issue: No additional add-ons implementable without changing the class (violation of the open-close principle!).

```
class Beverage:
    _name = "beverage"
    _cost = 0.00

    def __init__(self, milk=False, sugar=False):
        self._milk = milk
        self._sugar = sugar

    def __str__(self):
        desc = self._name
        if self._milk:
            desc += ", with milk"
        if self._sugar:
            desc += ", with sugar"
        return desc

    @property
    def cost(self):
        cost = self._cost
        if self._milk:
            cost += 0.30
        if self._sugar:
            cost += 0.20
        return cost
```

Decorator Pattern – Implementation

Solution:

- Create a class that wraps a beverage and behaves like a beverage itself. (i.e. implements the beverage interface)
- Possibility to create a chain of decorators.
- Composition solves the problem.
- Downside: Need to implement all functions of beverage even if they do not need to be changed.

```python
class Milk:
    def __init__(self, beverage):
        self.base = beverage

    def __str__(self):
        return f"{self.base}, with milk"

    @property
    def cost(self):
        return self.base.cost + 0.30

coffee_with_milk = Milk(Coffee())
```

Strategy Pattern

Strategy Pattern – Motivation (I)

Let's implement a duck . . .

```python
class Duck:
    def __init__(self):
        # stateless class for simplicity
        pass

    def quack(self):
        print("Quack!")

    def display(self):
        print("Boring looking duck.")

    def take_off(self):
        print("Run fast, flap wings.")

    def fly_to(self, destination):
        print("Fly to", destination)

    def land(self):
        print("Extend legs, touch down.")
```

Strategy Pattern – Motivation (II)

. . . and different types of ducks!

Oh, no! The rubber duck should not fly! We need to overwrite all the methods about flying.

- What if we want to introduce a `DecoyDuck` as well?
- What if a normal duck suffers a broken wing?

⇒ It makes more sense to abstract the flying behaviour.

```python
class RedheadDuck(Duck):
    def display(self):
        print("Duck with a read head.")

class RubberDuck(Duck):
    def quack(self):
        print("Squeak!")

    def display(self):
        print("Small yellow rubber duck.")
```

Strategy Pattern – Implementation (I)

- Create a class to describe the flying behaviour (flying strategy). . .
- . . . give `Duck` an instance of it . . .
- . . . and handle all the flying stuff via this instance

```python
class FlyingBehavior:
    def take_off(self):
        print("Run fast, flap wings.")
    def fly_to(self, destination):
        print("Fly to", destination)
    def land(self):
        print("Extend legs, touch down.")

class Duck:
    def __init__(self):
        self.flying_behavior = FlyingBehavior()
    def take_off(self):
        self.flying_behavior.take_off()
    def fly_to(self, destination):
        self.flying_behavior.fly_to(destination)
    def land(self):
        self.flying_behavior.land()
    # display, quack as before...
```

Strategy Pattern – Implementation (II)

- Other example of composition over inheritance.
- Encapsulation of function implementation in the strategy object.
- Useful pattern to *e.g.* define optimisation algorithm at runtime.

```python
class NonFlyingBehavior(FlyingBehavior):
    def take_off(self):
        print("It's not working :-(")
    def fly_to(self, destination):
        raise Exception("I'm not flying.")
    def land(self):
        print("That won't be necessary.")

class RubberDuck(Duck):
    def __init__(self):
        self.flying_behavior = NonFlyingBehavior()
    def quack(self):
        print("Squeak!")
    def display(self):
        print("Small yellow rubber duck.")

class DecoyDuck(Duck):
    def __init__(self):
        self.flying_behavior = NonFlyingBehavior()
    # different implementation for display/quack
```

Take-aways

- Object-oriented programming offers a powerful paradigm to structure your code.
- Inheritance, design principles and patterns allow to avoid repetitions (DRY).
- But do not overcomplicate things and always ask yourself if applying a particular functionality makes sense in the given context!

I COULD RESTRUCTURE THE PROGRAM'S FLOW
OR USE ONE LITTLE 'GOTO' INSTEAD.
EH, SCREW GOOD PRACTICE. HOW BAD CAN IT BE?
goto main_sub3;
COMPILE