Scientific Software Development with Python

Object oriented programming — Part 1

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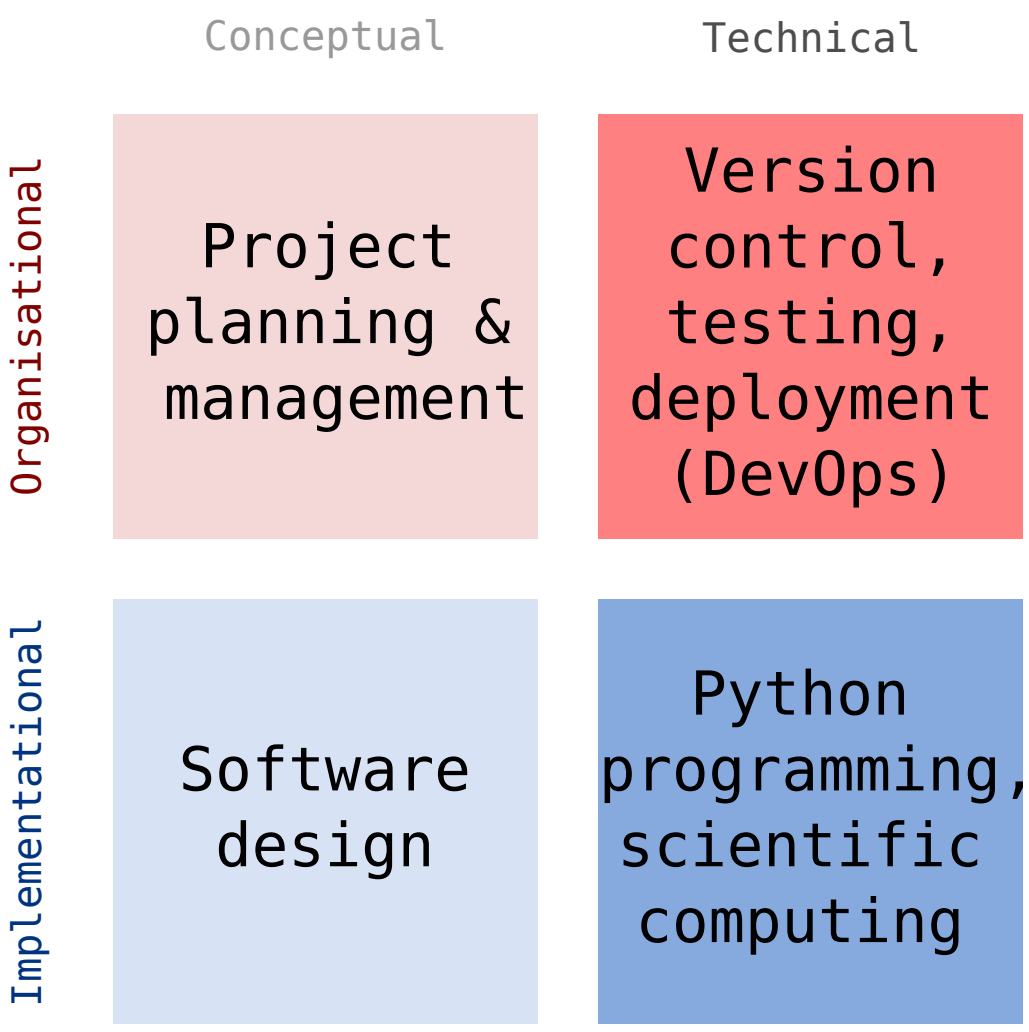
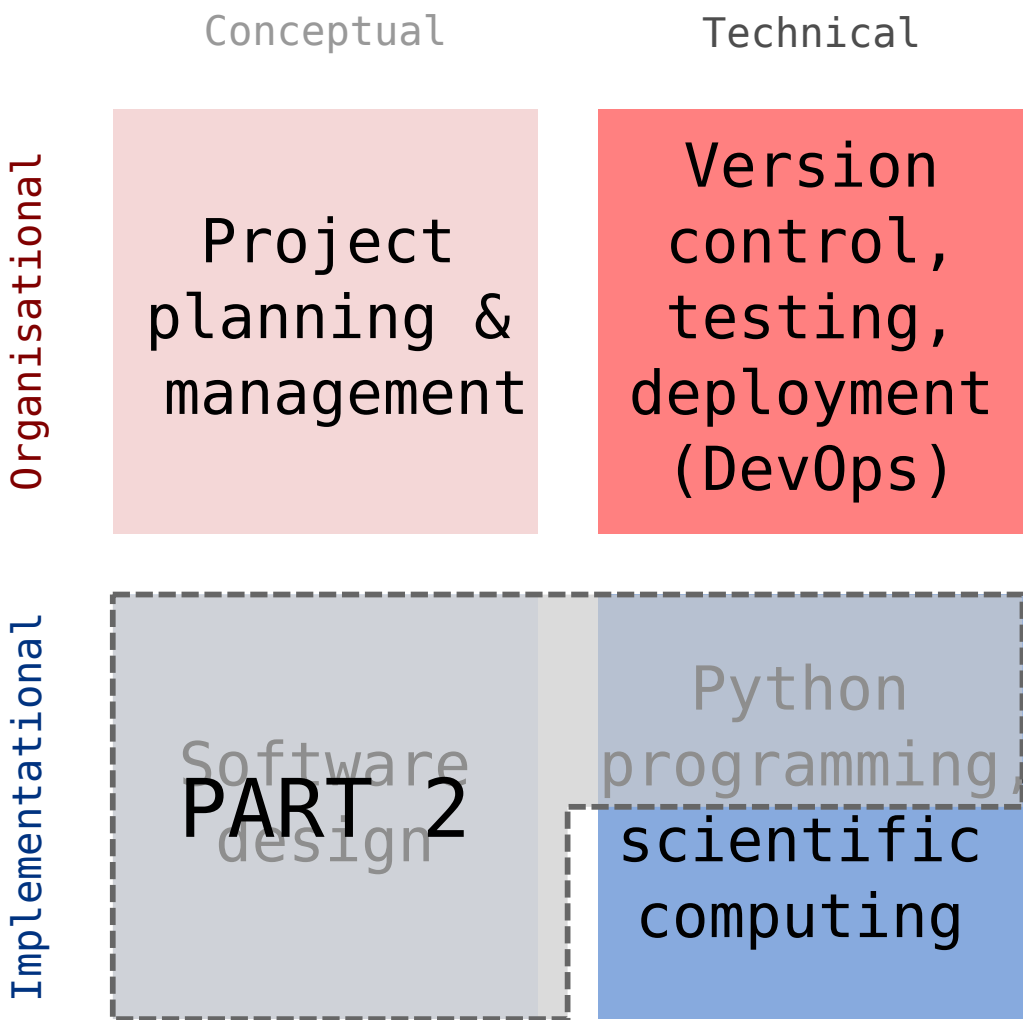
Agenda

1. Overview
2. Object oriented thinking
3. Classes
4. Inheritance
5. Aggregation and composition


Conceptual
Technical
Organisational
Implementational
Project planning & management
Version control, testing, deployment (DevOps)
Software design
Python programming, scientific computing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PART 2

This lecture

- Example of object oriented design
- Object oriented programming in Python
- Principle of object oriented programming

Next lecture

- Specifying interfaces using abstract classes
- Common Python design patterns
- Structural vs. object oriented programming

Agenda

- Modeling approach
- Processes are modeled using interacting objects.
- A class describes a type of object.
- Objects of a given class are called *instances*.

Example: Drawing diagrams

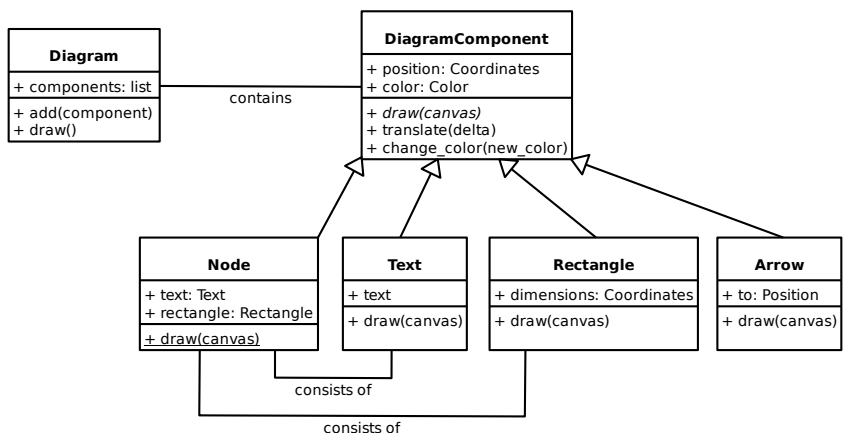
- Objects: Figure, rectangles, text, arrows
- Actions:
  - add rectangle
  - add text to rectangle
  - draw arrow from rectangle to rectangle

Unified modeling language (UML)

- Graphical modeling language
- Formal application quite complex
- But: Useful and intuitive way to communicate class relations

Example: Drawing diagrams

- Corresponding UML class diagram:



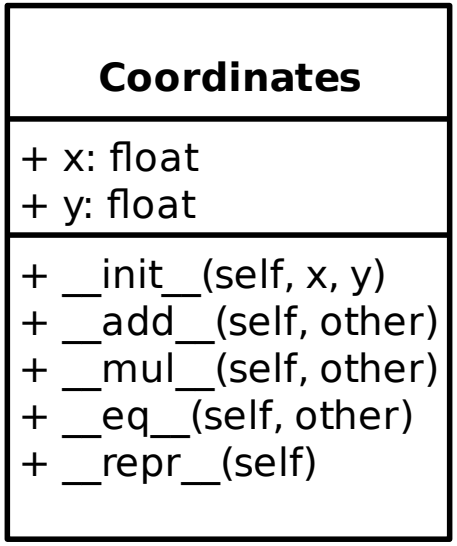
Unified modeling language (UML)

- UML class diagrams visualize classes and their relationships.
- Can be mapped directly to code.

So how can we map the different components of a UML diagram to Python?

Classes

- Block represents class
- Top: Class name
- Middle: Attributes (data)
- Bottom: Methods (actions)



Agenda

Classes in Python

- Defined using the `class` keyword.
- Definition consists of class methods.
- `__init__` function used to initialize new object[1].

```
class Coordinates:
    """
    The coordinate class represents two-dimensional, Cartesian
    coordinates.
    ...
    """
    def __init__(self, x, y):
        """
        Create pair of coordinates.
        ...
        """
        self.x = x
        self.y = y
    ...
```

[1] There's also the `__new__` function, which is called when a new object is created, but its usage is quite advanced.

Methods

- Methods are functions that act on class objects.
- General syntax:

```
object.method_name(arg_1, arg_2, ...)
```

  - Calls method `method_name` defined in `object`'s class with arguments `object, arg_1, arg_2, ...`

The object whose method is called upon is always passed as the first argument (`self`) to the class method. **This is how the method gains access to the class attributes.**

Attributes

- Attributes represent the specific properties (data) of a class instance.
- Attributes *should be set in* `__init__` *method*.
- But: This is not enforced. Attributes can be defined dynamically:

```
coordinates = Coordinates(1.0, 2.0)
print(coordinates.z) # Error
coordinates.z = 3.0
print(coordinates.z) # Prints: 3
```

Attribute access

- In contrast to other language, Python does not restrict access to class attributes
- **But**: Python does apply name mangling to attributes starting with two undescores[2]:

```
class A:
    def __init__(self):
        self.__attribute = 1

a = A()
print(a.__attribute) # Error
print(a._A__attribute) # Prints: 1
```

- Convention: Attributes prefixed with 1 underscore (_) should not be accessed from the outside.

[2] The attribute name becomes `_<class_name><attribute_name>`.

Attributes

- An alternative way of defining attributes in Python is to use the `@property` decorator:
- The function marked with `@property` is called when `obect.function_name` is accessed
- The function marked with `@<property_name>.setter` is called when a value is assigned to `object.<property_name>`

```
class Number:
    def __init__(self, number):
        self._number = number

    @property
    def plus_one(self):
        return self._number + 1

    @plus_one.setter
    def plus_one(self, plus_one):
        self._number = plus_one - 1
```

Example

```
number = Number(1)
print(number.plus_one) # Print: 2
number.plus_one = 1
print(number.plus_one) # Print: 1
print(number._number)  # Print: 0
```

Advantages

- The `@property` decorator allows defining getter and setter mehtods for Python attributes
- Allows computing properties on the fly (dynamic attributes)
- Omitting the setter make the attribute read-only
- Setter can be used to check validity of value

Static methods

- Static methods are methods that do not depend on a specific object and can therefore be called directly on the class
- Static methods are defined using the `@staticmethod` decorator[3, 4]

Example

```
class Color:
    @staticmethod
    def Black():
        return Color("#000000")
    ...
    def __init__(self, color_code):
        self.color_code = color_code

black = Color.Black()
```

[3] We'll learn more about decorators later.

[4] There's also the `@classmethod` decorator, which serves a similar purpose

Special class methods

- Python uses magic (or dunder) methods to implement special functionality (syntactic sugar):
  - `__repr__(self)`: Used to print output in interpreter.
  - `__str__(self)`: Called by `print` and `str` methods. Will use `__repr__` is defined.
  - `__add__(self, other)`: Implements + operator
  - `__mul__(self, other)`: Implements * operator
  - `__eq__(self, other)`: Implements == operator
- All special syntax in Python is implemented in this way[5]

[5] See official docs or `https://levelup.gitconnected.com/python-dunder-methods-ea98ceabad15` for an overview.

Exercise

- Exercise 1 in exercise notebook
- Time: 10 minutes

Brief summary

What we have learned:

- Classes define types of objects with given properties and actions
- How to define class methods in Python
- Two ways to define class attributes in Python
- How to define static and special methods

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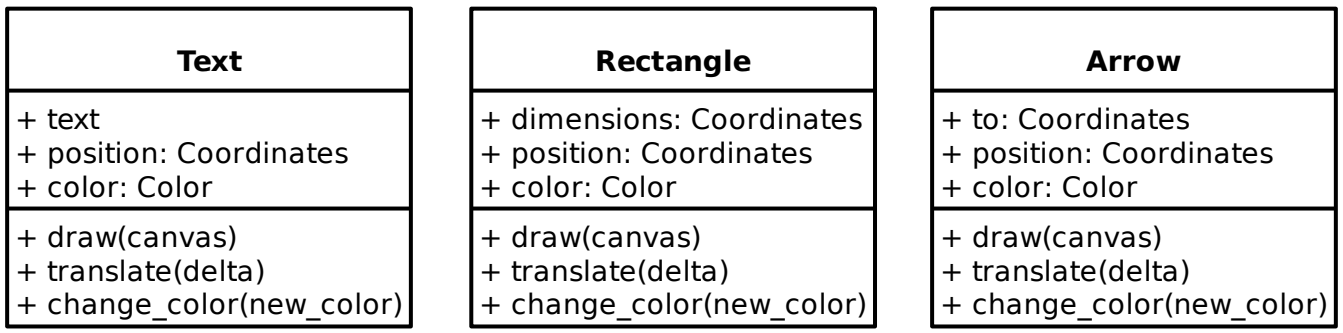
3. Classes
4. **Inheritance**
5. Aggregation and composition

Moving on with the design

- Let's add classes for the object we would like to draw:



Problem

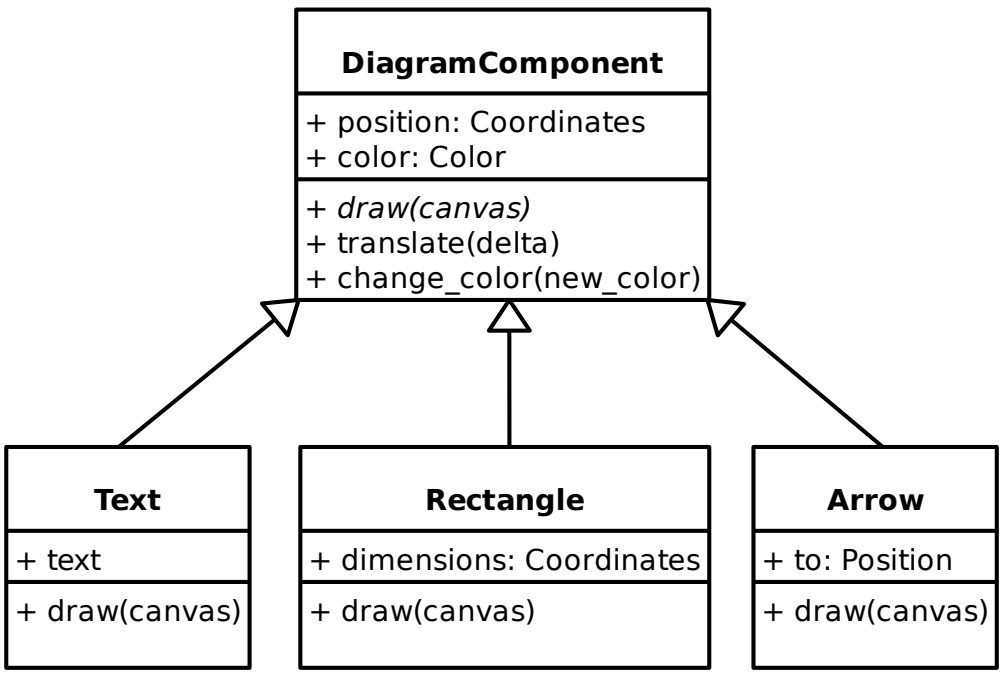
All classes have `position` and `color` attributes as well as `translate` and `change_color` functions, that do the same.

The DRY principle

- **Do not Repeat Yourself**
- Every piece of knowledge must have a single, unambiguous, authoritative representation within a system
- Duplicate code will sooner or later become inconsistent

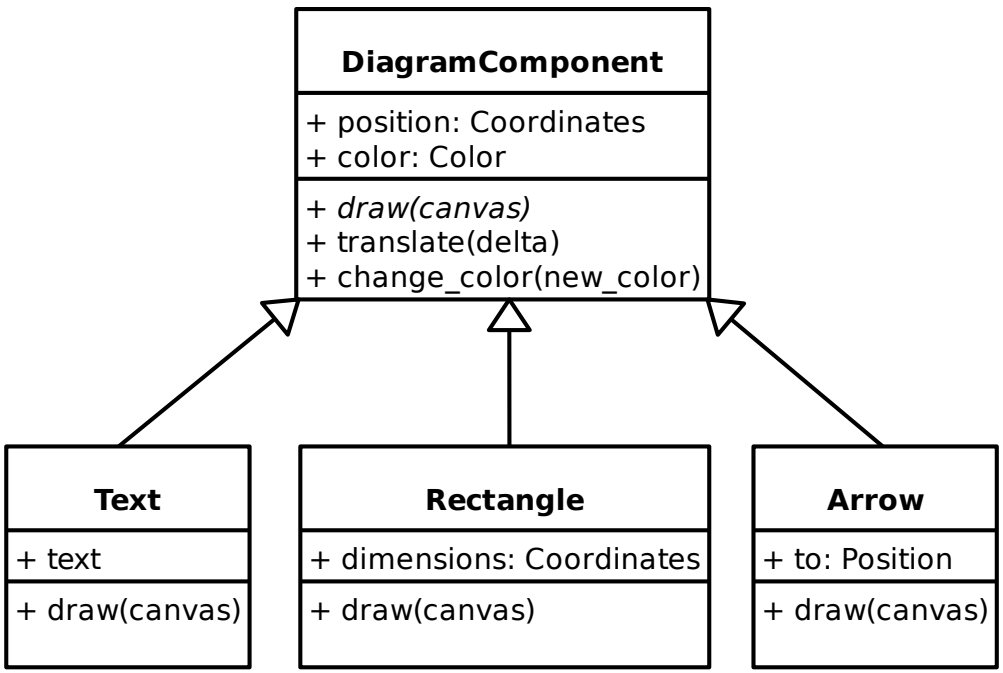
Inheritance

- Represents a *is a* relationship.
- *Child class* inherits from *base class*.
- The child class inherits all *methods and attributes* from its parent.



Inheritance in UML

- Represented by arrow with hollow head
- The arrow represents a *generalization* relation.



Inheritance in Python

- Basic syntax:

```
class ChildClass(BaseClass):
    def __init__(self, ...):
        super().__init__(...) # Calls __init__ of BaseClass
    ...
```

- All functions defined in `BaseClass` are available in `ChildClass`.

Important

`__init__` function of child class must call `__init__` function of base class to ensure object is properly initialized.[6]

[6] Exceptions are classes that don't define any attributes and therefore don't need to be initialized.

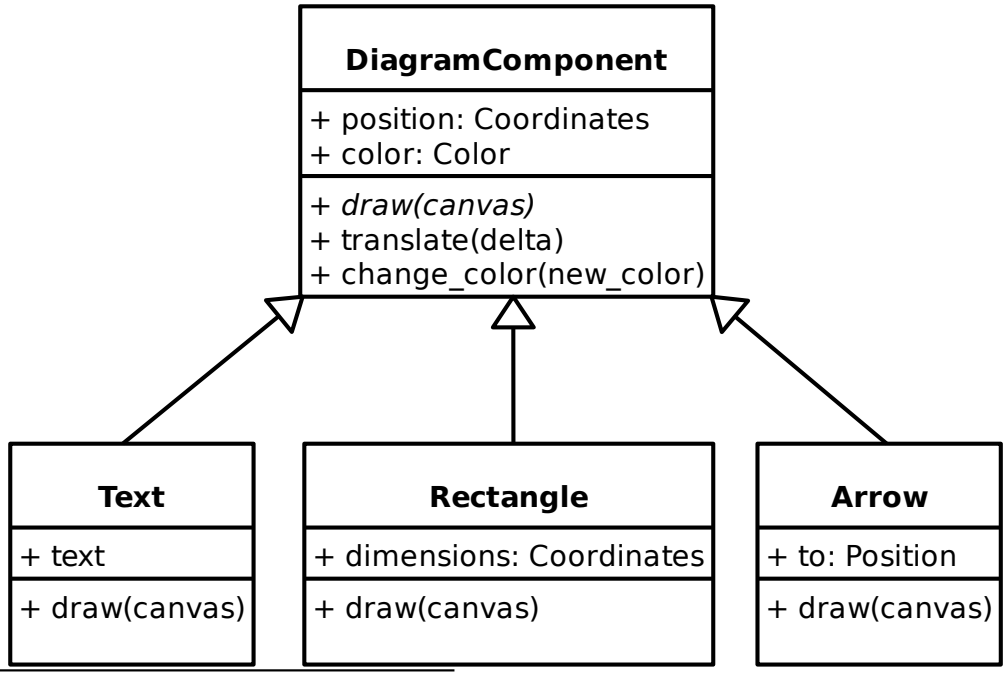
Overriding

- If the child class redefines a method of the base class, it *overrides* the implementation of the base class

```
class A:
    def print_class(self):
        print("A")

    def print_base(self):
        print("A")

class B(A):
    def print_class(self):
        print("B")

b = B()
b.print_class() # Prints: B
b.print_base()  # Prints: A
```

Overriding

- The `draw` method in the `DiagramComponent` class is an abstract method[7].
- An abstract method is a method that *must* be overridden by the child classes.



[7] Illustrated by italic function name in UML diagram.

Polymorphism

- Polymorphism is when a functions executes different code based the object types of its arguments

```
object = Rectangle(...)
object.draw(canvas) # Draws a rectangle
object = Text(...)
object.draw(canvas) # Draws text
object = Arrow(...)
object.draw(canvas) # Draws an arrow
```

- Python achieves polymorphism through *duck typing*.[8]

[8] "If it walks like a duck and it quacks like a duck, then it must be a duck."

Multiple inheritance

- *If you think you need multiple inheritance, you're probably wrong, but if you know you need it, you might be right.*[9]
- Python allows classes to inherit from multiple base classes:

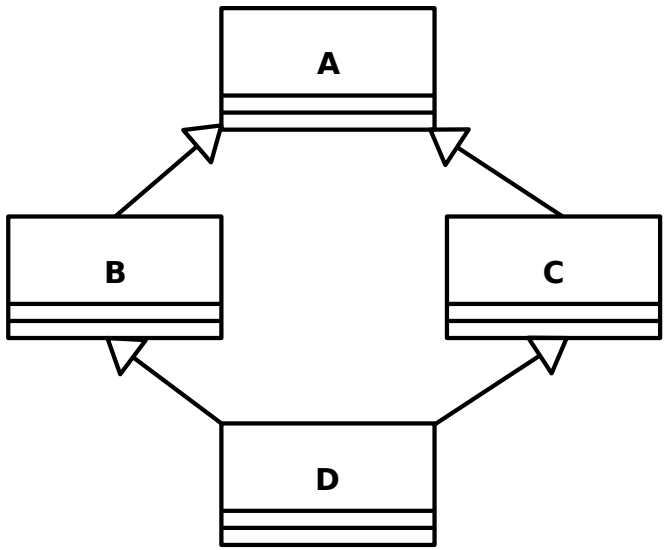
```
class A:
    def print_a(self):
        print("A")

class B:
    def print_b(self):
        print("A")

class C(A, B):
    pass

c = C()
c.print_a() # Prints "A"
c.print_b() # Prints "B"
```

[9] Phillips, Dusty. Python 3 object oriented programming.

The diamond problem

- Things get messy, when multiple base classes share a common ancestor

```
class A:
    def __init__(self):
        print("Initializing A ...")

class B(A):
    def __init__(self):
        super().__init__()
        print("Initializing B ...")

class C(A):
    def __init__(self):
        super().__init__()
        print("Initializing C ...")

class D(B, C):
    def __init__(self):
        super().__init__()
```



The diamond problem

- How can we know which `__init__` function is called?

```
d = D()
```

- Output:

```
Initializing A ...
Initializing C ...
Initializing B ...
```

- `super()` linearizes the class hierarchy and calls all functions in sequence, so this works.
- **But:** This becomes problematic when these functions take different parameters.

Mixin classes

- A mixin class is a super class that only implements functionality (no attributes) and can be easily added to a class.

```
class PrettyPrint:
    class pretty_print(self):
        print(f"~~ {self} ~~")

class A(PrettyPrint):
    def __str__(self):
        return "A"

a = A()
a.pretty_print() # Prints: ~~ A ~~
```

Exercise

- Exercise 2 in exercise notebook
- Time: 15 minutes

Summary

What we have learned:

- Inheritance allows different objects to share common code
- How to achieve polymorphism using inheritance and overriding
- How to implement inheritance in Python
- The difficulties of multiple inheritance and when it is useful (Mixins)

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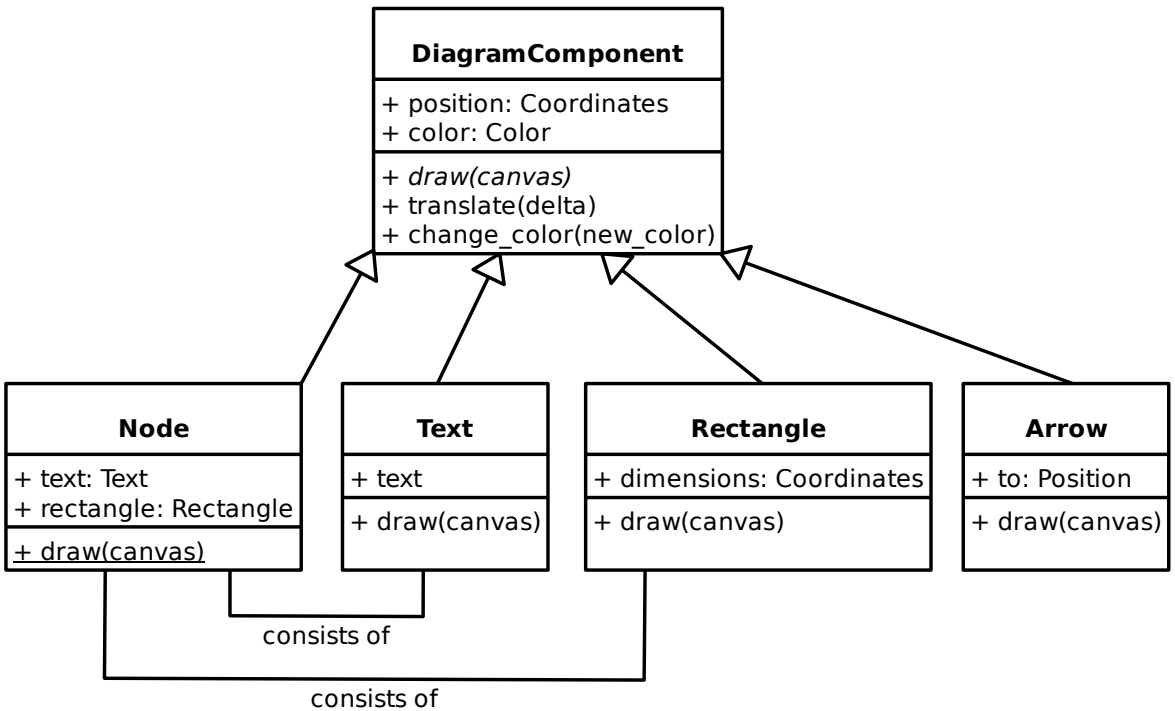
5. **Aggregation and composition**

Composition

- A node *consists of* a rectangle and a text.
- Objects are in a composition relation when their lifetimes are dependent on each other.

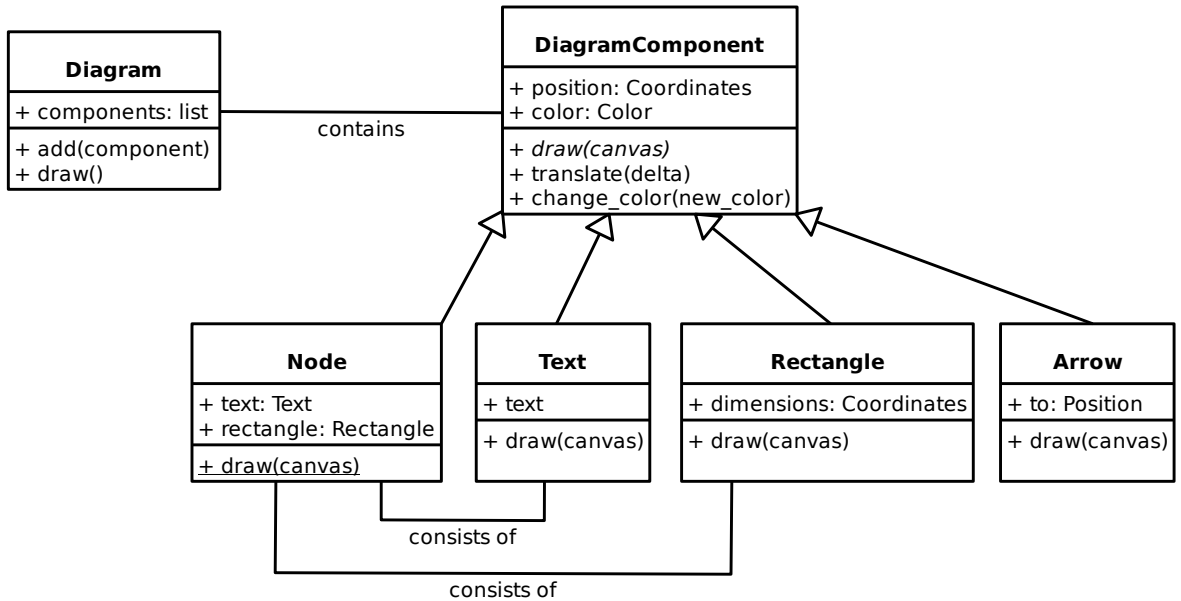


Composition as abstraction

- {Abstraction: Dealing with the level of detail that is most appropriate to a given task}
- Manually creating a node from a rectangle and text is complex and error prone:
  - Text must be placed correctly, both rectangle and text must be drawn on diagram.
- `Node` class hides a way information (the rectangle and text) to simplify creation of diagram nodes.

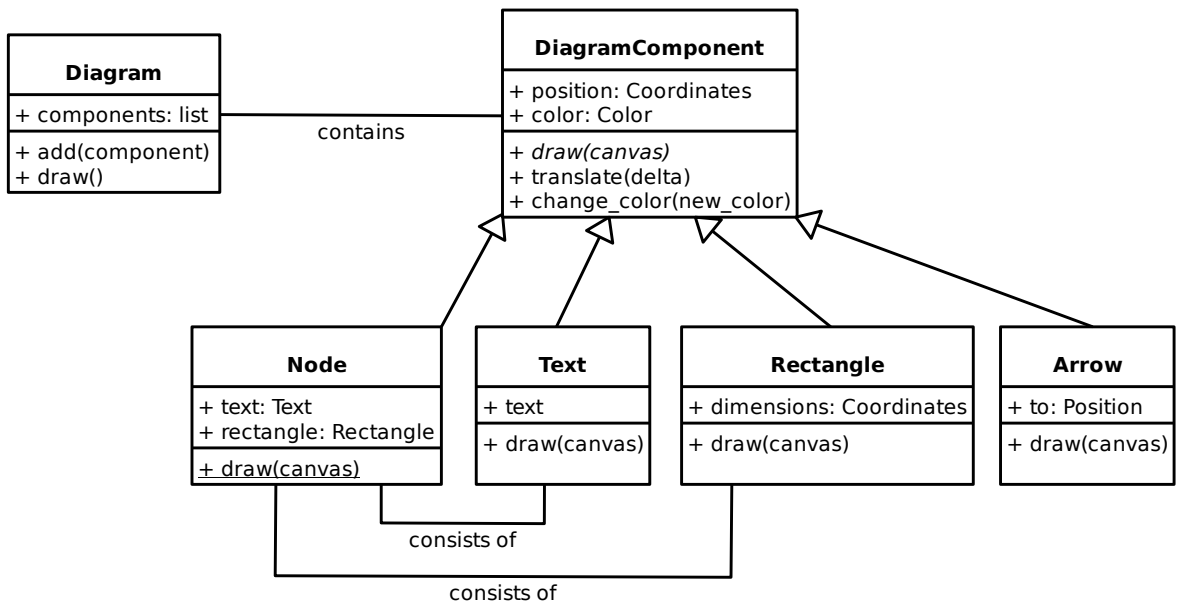
Finalizing the design

- The diagram class collects and draws the components of the diagram.



The aggregation relation

- Two objects are in an aggregation relation if one *contains* the other but when their lifetimes are independent
- Example: A given node may appear in multiple diagrams.
- Difference to composition is mostly formal.



Exercise

- Exercise 3 in exercise notebook
- Time: 15 minutes

Summary