Abstract Data Types (II)
(and Object-Oriented Programming)

Jordi Cortadella and Jordi Petit
Department of Computer Science

Public or private?

- What should be public?
  - Only the methods that need to interact with the external world. Hide as much as possible. Make a method public only if necessary.
- What should be private?
  - All the attributes.
  - The internal methods of the class.
- Can we have public attributes?
  - Theoretically yes (Python and C++ allow it).
  - Recommendation: never define a public attribute.
- Observation: Python does not support public/private attributes and methods. There is no protection to prevents a bad use.
- The naming conventions (underscores) are used to distinguish them.

Class Point: a new implementation

- Let us assume that we need to represent the point with polar coordinates for efficiency reasons (e.g., we need to use them very often).
- We can modify the private section and the implementation of the class without modifying the specification of the public methods.
- The API (a contract between designers and users) should not be modified.
- Do you know what a *deprecated* method is?
  - Not recommended, possibly superseded by another method
  - Likely to be removed or discontinued in the future

Class Point: a new implementation

```
class Point:
    """A class to represent and operate with two-dimensional points"""

    # Declaration of attributes (recommended for type checking)
    _radius: float # radius of the polar coordinates
    _angle: float # angle of the polar coordinates

    def __init__(self, x: float = 0, y: float = 0):
        """Constructor with x and y coordinates"""
        self._radius = math.sqrt(x*x + y*y)
        self._angle = 0 if x == 0 and y == 0 else math.atan2(y/x)

    def x(self) -> float:
        """Returns the x coordinate"""
        return self._radius*math.cos(self._angle)

    def y(self) -> float:
        """Returns the y coordinate"""
        return self._radius*math.sin(self._angle)

    def distance(self, p: Optional['Point']) -> float:
        """Returns the distance to point p
           (or the distance to the origin if p is None)"""
        dx, dy = self.x(), self.y()
        if p is not None:
            dx -= p.x()
            dy -= p.y()
        return math.sqrt(dx*dx + dy*dy)
```

Works without any change (but it can be done more efficiently)

Class Point: a new implementation

```
    def angle(self) -> float:
        """Returns the angle of the polar coordinates"""
        return self._angle

    def __add__(self, p: 'Point') -> 'Point':
        """Returns a new point by adding the coordinates of two points.
           This method is associated to the + operator"""
        return Point(self.x() + p.x(), self.y() + p.y())

    def __eq__(self, p: 'Point') -> bool:
        """Checks whether two points are equal.
           This method is associated to the == operator"""
        return self.x() == p.x() and self.y() == p.y()
```

Discussion:

- How about using `_x` and `_y` (or `_radius` and `_angle`) as "public" attributes?
- Programs using `p._x` and `p._y` would not be valid for the new implementation.
- Programs using `p.x()` and `p.y()` would still be valid.

Recommendation:

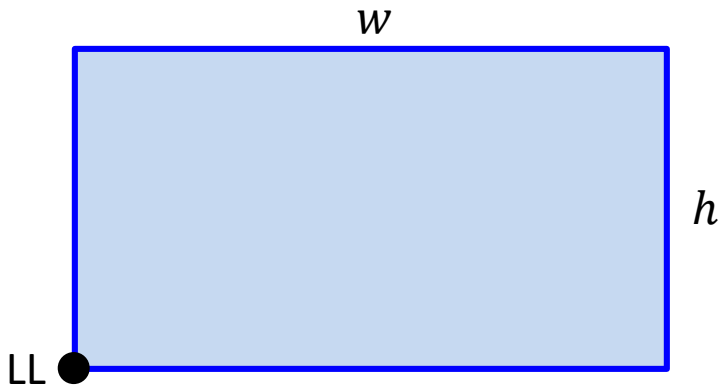
- All attributes should be ***private***.

A new class: Rectangle

- We will only consider rectilinear rectangles (axis-aligned).

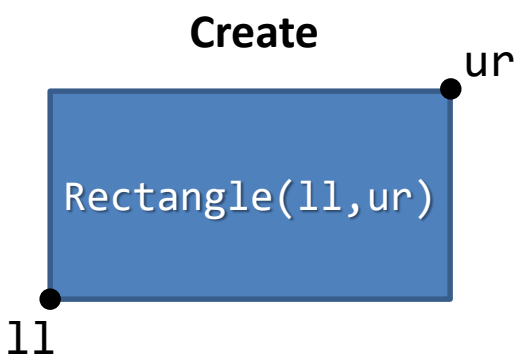
- A rectilinear rectangle can be represented in different ways:

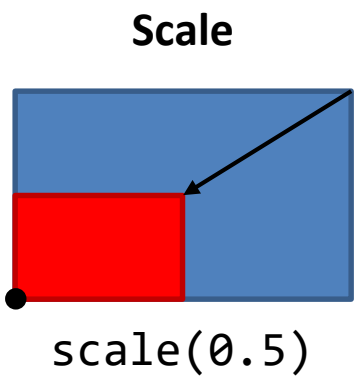
Two points (extremes of diagonal)

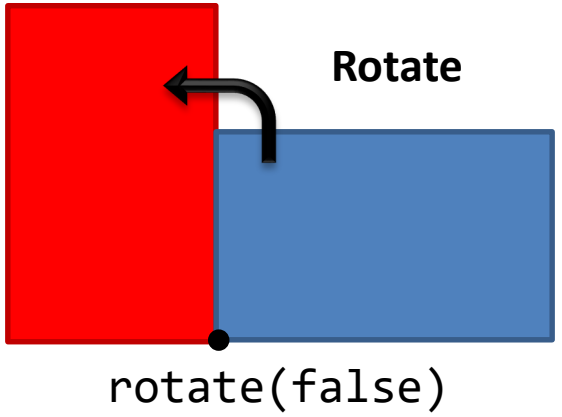


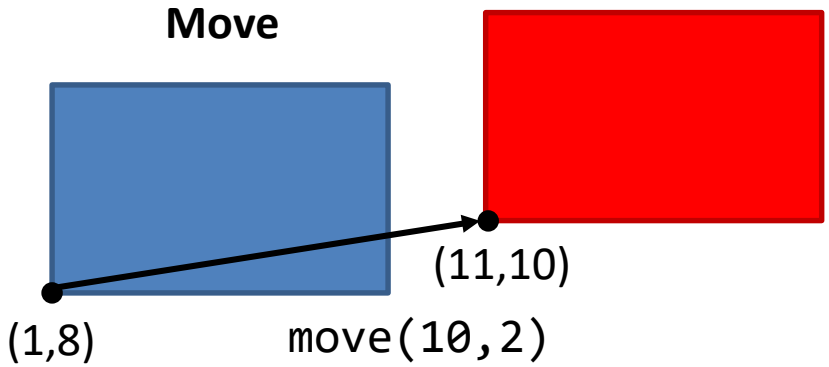
One point, width and height

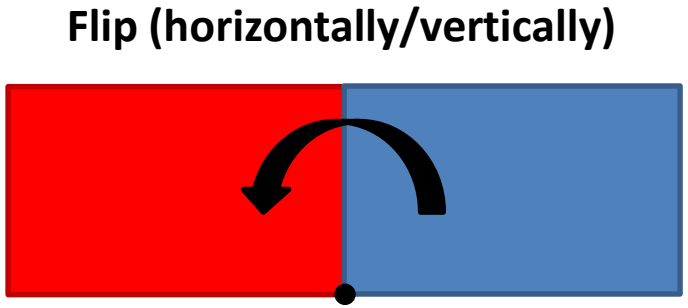
Rectangle: abstract view

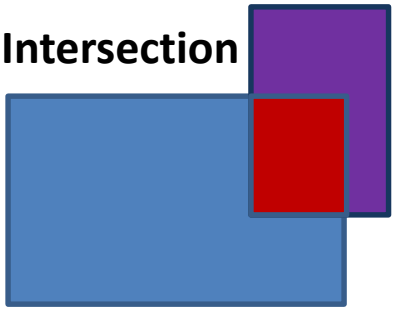


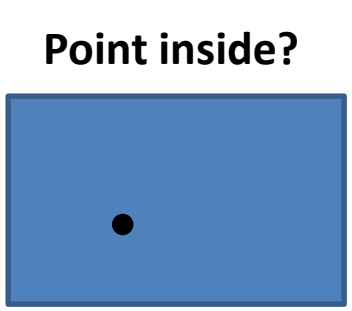












Rectangle: ADT (incomplete)

```
from point import Point


class Rectangle:
    """Class to operate with rectilinear rectangles"""

    def __init__(self, ll: Point, ur: Point):
        """Constructor using the LL and UR corners"""
        ...

    def area(self) -> float:
        """Returns the area of the rectangle"""
        ...

    def scale(self, s: float) -> None:
        """Scales the rectangle with a factor s > 0"""
        ...

    def __mul__(self, r: 'Rectangle') -> 'Rectangle':
        """Returns the intersection with another rectangle"""
        ...
```

Rectangle: using the ADT

```
# Creates a rectangle 4x5
r1 = Rectangle(Point(0,0), Point(4,5))

# Creates a rectangle 8x4
r2 = Rectangle(Point(0,0), Point(8,4))

r1.move(2, 3)  # Moves the rectangle
r1.scale(1.2)  # Scales the rectangle
area1 = r1.area()  # Calculates the area

r3 = r1*r2;

if r3.empty(): …
```

Rectangle: ADT

```
from point import Point


class Rectangle:
    """Class to operate with rectilinear rectangles"""

    # Private attributes to represent a rectangle
    _ll: Point  # Lower-left corner of the rectangle
    _w: float  # width of the rectangle (>= 0)
    _h: float  # height of the rectangle (>= 0)

    def __init__(self, ll: Point, ur: Point):
        """Constructor using the LL and UR corners"""
        assert ll.x() <= ur.x() and ll.y() <= ur.y()
        self._ll = Point(ll.x(), ll.y())
        self._w = ur.x() - ll.x()
        self._h = ur.y() - ll.y()
```

Note: Python does not support function overloading. Classes can only have one constructor.

Rectangle: ADT

```
class Rectangle:
                        ⋮
    def width(self) -> float:
        """Returns the width of the rectangle"""
        return self._w

    def height(self) -> float:
        """Returns the height of the rectangle"""
        return self._h

    def ll(self) -> Point:
        """Returns the LL corner of the rectangle"""
        return Point(self._ll.x(), self._ll.y())

    def ur(self) -> Point:
        """Returns the UR corner of the rectangle"""
        return self._ll + Point(self.width(), self.height())
```

Discussion: what if `ll()` would return `self._ll` (instead of a copy)?

Rectangle: ADT

```
class Rectangle:
                              ⋮
    def area(self) -> float:
        """Returns the area of the rectangle"""
        return self.width()*self.height()

    def scale(self, s: float) -> None:
        """Scales the rectangle by s,
           keeping the LL corner fixed"""
        self._w *= s
        self._h *= s

    def empty(self) -> bool:
        """Checks whether the rectangle is empty"""
        return self.area() <= 0  # Gives some tolerance
```

Rectangle: ADT

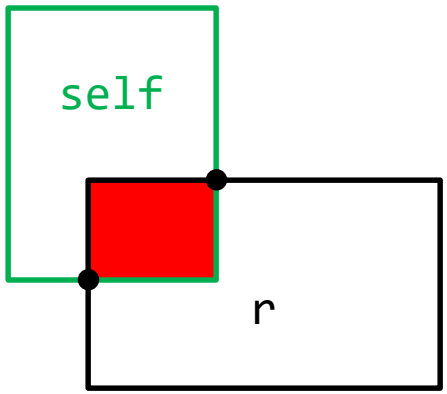
```
class Rectangle:
                        ⋮
    def __mul__(self, r: 'Rectangle') -> 'Rectangle':
        """Returns the intersection of two rectangles"""

        # Calculate the ll coordinates
        r1ll, r2ll = self.ll(), r.ll()
        ll_x = max(r1ll.x(), r2ll().x())
        ll_y = max(r1ll.y(), r2ll().y())

        # Calculate the ur coordinates
        r1ur, r2ur = self.ur(), r.ur()
        ur_x = min(r1ur.x(), r2ur().x())
        ur_y = min(r1ur.y(), r2ur().y())

        # Check if no intersection: return empty rectangle
        if ur_x <= ll_x or ur_y <= ll_y:
            return Rectangle(Point(0,0), Point(0,0))

        return Rectangle(Point(ll_x, ll_y), Point(ur_x, ur_y))
```



Let us work with rectangles

```
r1 = Rectangle(Point(2,3), Point(6,8))
area1 = r1.area()  # area1 = 20

r2 = Rectangle(Point(3,5), Point(5, 9))

# Check whether the point (4,7) is inside the
# intersection of r1 and r2.
in = (r1*r2).isPointInside(Point(4,7))

r2.rotate(false)  // r2 is rotated counterclockwise
r2 *= r1;         // Intersection with r1
```

Exercise: draw a picture of R1 and R2 after the execution of the previous code.

A Python session with rational numbers

```
>>> from rational import Rational  # from file rational.py
>>> a = Rational(4, -6)        # construct with num and den
>>> print(a)
-2/3
>>> b = Rational(4)  # integer value
>>> print(b)
4
>>> print((a+b).num(), (a+b).den())
10 3
>>> c = Rational()  # c = 0
>>> if a < c:
...     print(a, "is negative")
...
-2/3 is negative
>>> print(a*b)  # uses the __str__ method (see later)
-8/3
>>> a/b  # uses the __repr__ method (see later)
Rational(-1/6)
>>>
```

The Rational class in Python

```
class Rational:
    """Class to represent rational numbers"""

    # Private attributes:
    # Invariant: _den > 0 and gcd(_num, _den) = 1
    _num: int  # numerator
    _den: int  # denominator (invariant: _den > 0)

    def __init__(self, num: int = 0, den: int = 1):
        assert den != 0

        self._num, self._den = num, den
        self._simplify()
```

The Rational class in Python

```
class Rational:
        ⋮
    def num(self) -> int:
        """Returns the numerator"""
        return self._num

    def den(self) -> int:
        """Returns the denominator"""
        return self._den

    def _simplify(self) -> None:   # Private method
        """Simplifies the representation"""
        if self._den < 0:
            self._num *= -1
            self._den *= -1
        d = math.gcd(abs(self._num), self._den)
        self._num //= d
        self._den //= d
```

Magic representation methods

```
class Rational:

        ⋮

  def __str__(self) -> str:
      """Returns a user-friendly string with information
      about the value of the object. It is invoked by
      str(x) or print(x)."""
      if self._den == 1:
          return str(self._num)
      return f"{self._num}/{self._den}"

  def __repr__(self) -> str:
      """Returns a string with information about the
      representation of the class. It is invoked by repr(x)
      or simply 'x'."""
      return f"Rational({self})"
```

Magic arithmetic methods

```
class Rational:

        ⋮

    def __neg__(self) -> 'Rational':
        """Returns -self."""
        return Rational(-self._num, self._den)


    def __add__(self, rhs: 'Rational') -> 'Rational':
        """Returns self + rhs."""
        num = self._num*rhs._den + self._den*rhs._num
        den = self._den*rhs._den
        return Rational(num, den)

    # Similarly for __sub__, __mul__, __truediv__
```

Magic relational methods

```
class Rational:

        ⋮

  def __eq__(self, rhs: 'Rational') -> bool:
      """Checks whether self == rhs."""
      return self._num == rhs._num and self._den == rhs._den

  def __ne__(self, rhs: 'Rational') -> bool:
      """Checks whether self != rhs."""
      return not self == rhs

  def __lt__(self, rhs: 'Rational') -> bool:
      """Checks whether self < rhs."""
      return self._num*rhs._den < self._den*rhs._num

  def __le__(self, rhs: 'Rational') -> bool:
      """Checks whether self <= rhs."""
      return not rhs < self

  # Similarly for __gt__ and __ge__
```

Python documentation: *docstrings*

```
>>> from rational import Rational
>>> help(Rational.__add__)
Help on function __add__ in module rational:

__add__(self, rhs)
    Returns self + rhs.
>>> help(Rational)
class Rational(builtins.object)
 |  Rational(num=0, den=1)
 |
 |  Class to represent rational numbers.
 |
 |  The class includes the basic arithmetic and relational
 |  operators.
 |
 |  Methods defined here:
 |
 |  __add__(self, rhs)
 |      Returns self + rhs.
 |
 |  __eq__(self, rhs)
 |      Checks whether self == rhs.
```

Python documentation: *docstrings*

- The first line after a module, class or function can be used to insert a string that documents the component.
- Triple quotes (""") are very convenient to insert multi-line strings.
- The ***docstrings*** are stored in a special attribute of the component named __doc__.
- Different ways of print the ***docstrings*** associated to a component:
  - `print(Rational.num.__doc__)`
  - `help(Rational.num)`

Designing a module: example

```
# geometry.py

"""geometry.py
Provides two classes for representing Polygons and Circles."""

# author: Euclid of Alexandria

from math import pi, sin, cos


class Polygon:

    """Represents polygons and provides methods to
    calculate area, intersection, convex hull, etc."""

    def __init__(self, list_vertices: list[Point]):
        """Creates a polygon from a list of vertices."""
    ...

class Circle:
    ...
```

Documentation of the module

Documentation of the class

Documentation of the method

Using a module: example

```
import geometry
p = geometry.Poligon(…)
c = geometry.Circle(…)
```

Imports the module. Now all classes can be used with the prefix of the module.

```
import geometry as geo
p = geo.Poligon(…)
c = geo.Circle(…)
```

Imports and renames the module.

```
from geometry import *
p = Poligon(…)
c = Circle(…)
```

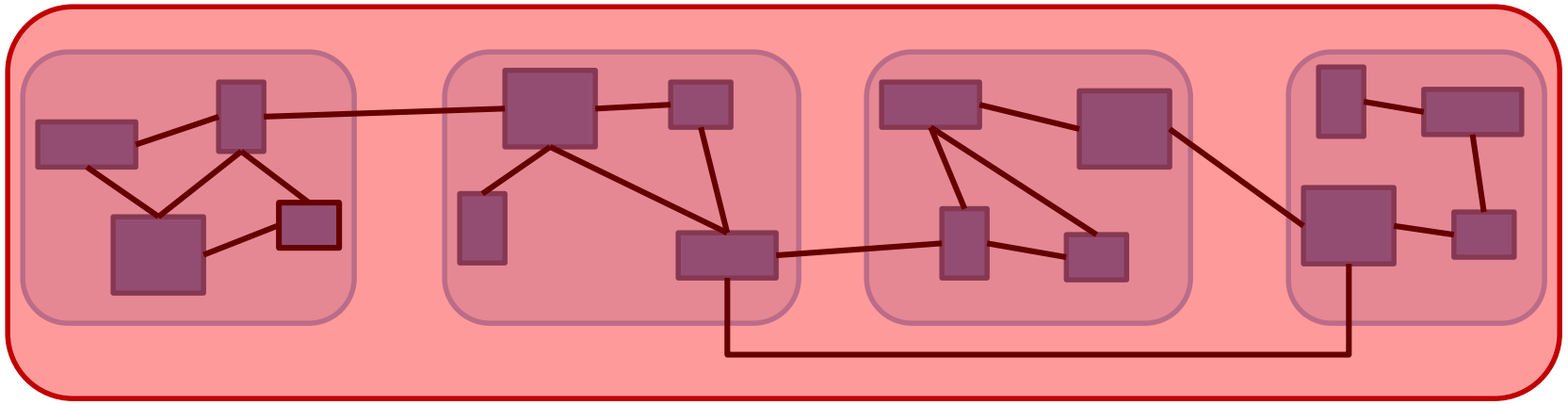
Imports all classes in the module. No need to add the prefix of the module.

```
from geometry import Poligon as plg, Circle as cir
p = plg(…)
c = cir(…)
```

Imports and renames the classes in the module.

Conclusions

- Finding the appropriate hierarchy is a fundamental step towards the design of a complex system.
- User-friendly documentation is indispensable.



EXERCISES

Implement methods

Implement the following methods for the class Rectangle:

```
def rotate(self, clockwise: bool) -> None:
    """Rotate the rectangle 90 degrees clockwise or counterclockwise,
       depending on the value of the parameter. The rotation should be
       done around the lower-left corner of the rectangle"""

def flip(self, horizontally: bool) -> None:
    """Flip horizontally (around the left edge) or vertically (around
       the bottom edge), depending on the value of the parameter."""

def isPointInside(self, p: Point) -> bool:
    """ Check whether point p is inside the rectangle"""
```

Re-implement a class

Re-implement the class Rectangle using an internal representation with two Points:

- Lower-Left (LL)
- Upper-Right(UR)

Make the minimum number of changes to **preserve the API** of the class.

Distance between rectangles

Implement the following method for the class Rectangle:

```
def distance(self, r: 'Rectangle') -> float:
    """Calculates the shortest distance between two rectangles.
       If two rectangles intersect, their distance is zero."""
```

Hint: try to make the code simple and elegant,
possibly defining some reusable private method.