Object-Oriented Programming In Mechatronic Systems

Summer School

Module 3
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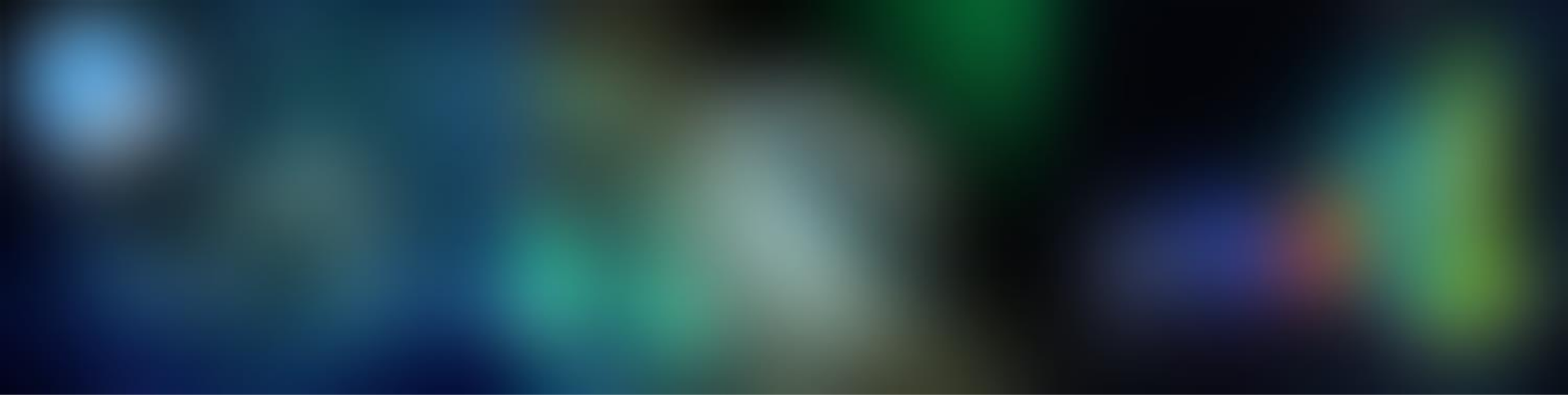
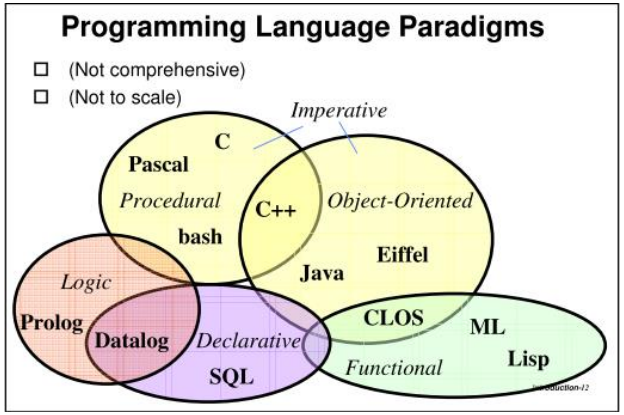


What is Object-Oriented Programming?

What is Object-Oriented Programming?

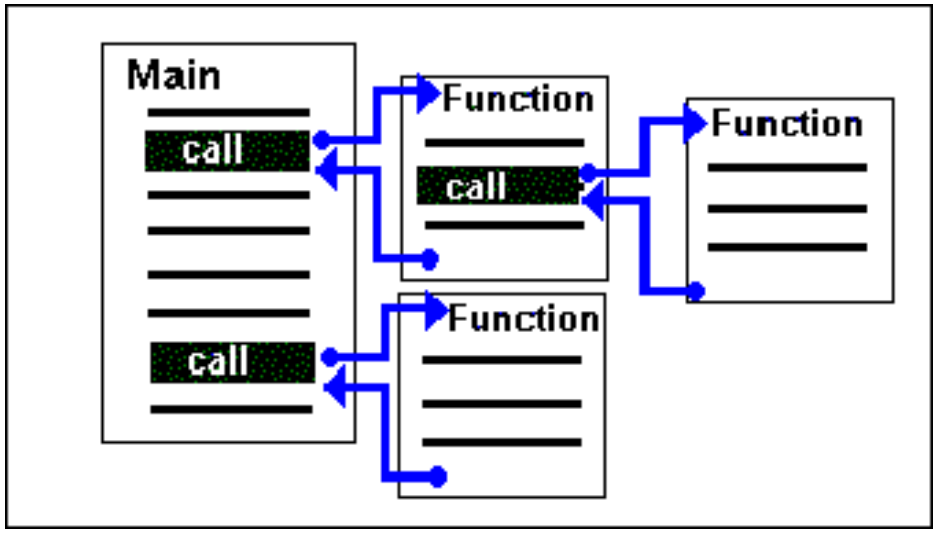
First of all: It is a programming paradigm!

- A programming paradigm can be understood as a **style**
- There are **many languages** and **several paradigms** out there!
- For instance **procedural**, **declarative** or **functional**
- … and of course: object-oriented programming (**OOP**), e.g. Java or C++
- Many languages support more then one paradigm (Java too!)

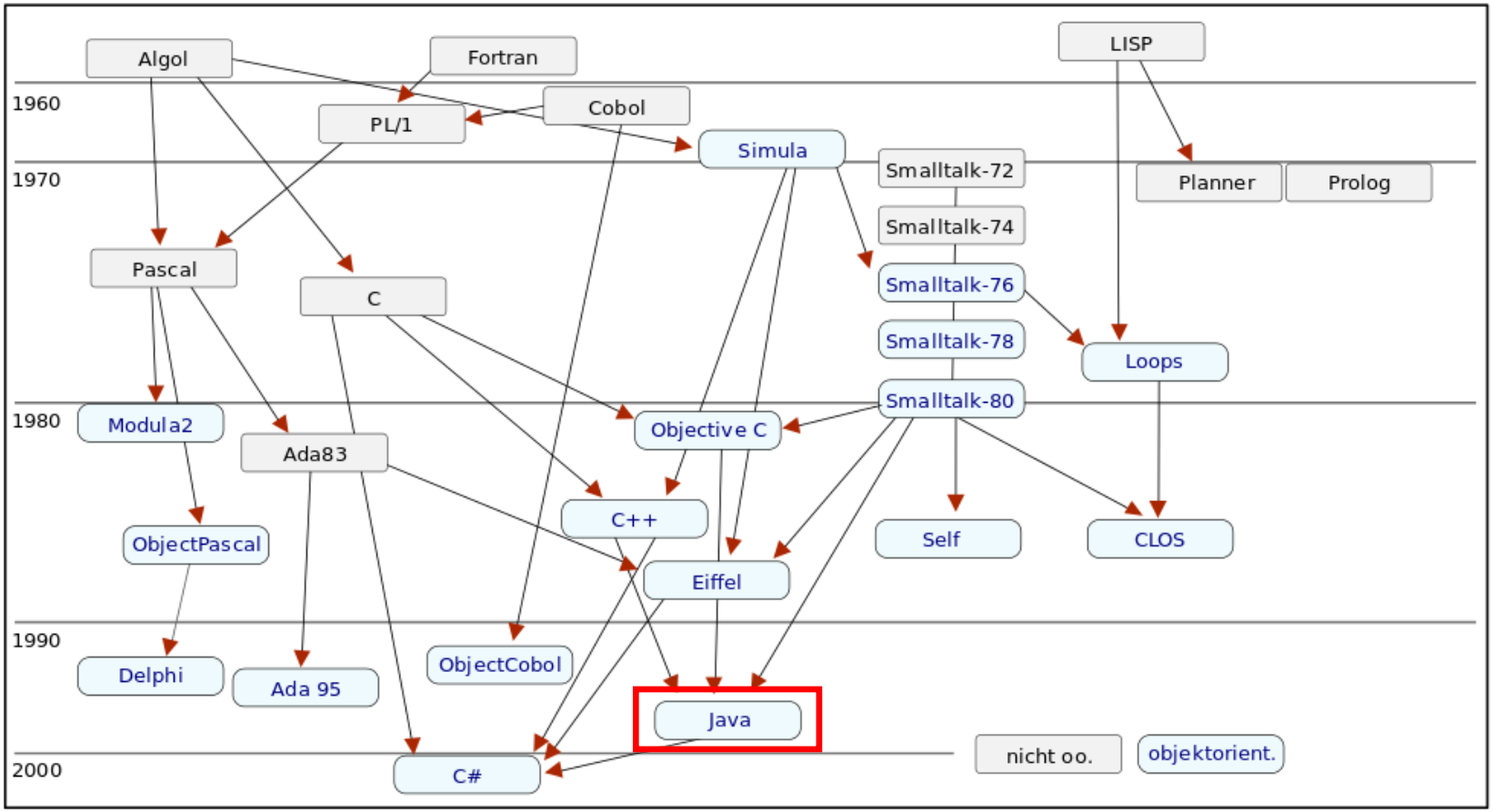


Excurse: Procedural programming

- **Core concept: Procedure calls**
- Procedures: routines, subroutines or functions
- Contain a series of computational steps to be carried out
- Any procedure can be called during the program's execution
- Including other procedures or itself
- **Examples: C or Pascal**



Excurse: Brief history of OOP languages



What is Object-Oriented Programming?

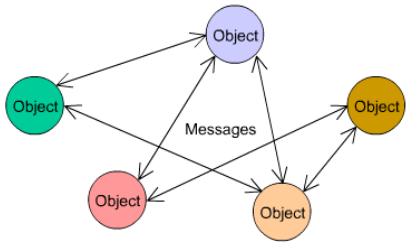
The core concept of OOP is the object!

Real-world objects have **two characteristics**:

1. **State**, e.g. a bicycle could have several states (e.g. gear, speed …)
2. **Behavior**, e.g. a bicycle could do things and behave differently (e.g. applying breaks)

Motivation for using OOP

- Software objects are **conceptually similar to real-world objects**
- They store their **state** in **fields** and **expose** their **behavior** through **methods**
- Objects **communicate** with each other by passing **“messages”**



Interaction of objects via message passing

What is Object-Oriented Programming?

Motivation for using OOP

- **Modularity**: Source code can be written and maintained independently
- **Information-Hiding**: Internal implementation remains hidden from the outside
- **Code Re-use**: If an object already exists this object can be used by you

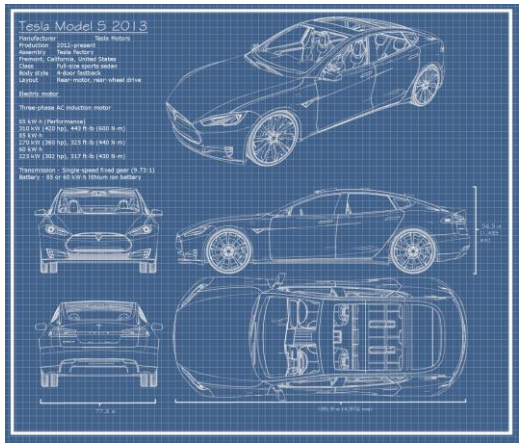
OOP vs Procedural Programming

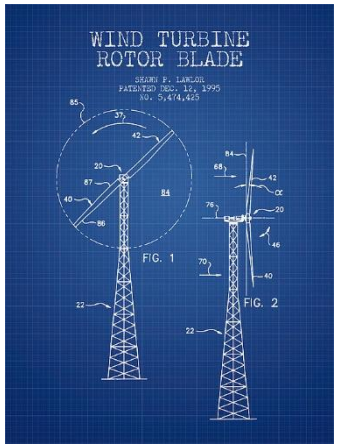
- Procedural programming uses **procedures** to operate on data structures
- … while in OOP they are bundled together
- An **object** operates on its **own** data structures!
- You can also use the procedural paradigm in Java!

What is Object-Oriented Programming?

What are classes?

- A template, a blueprint - it’s **not** a concrete realization of something!
- Think of a **concept**!
- And **you need a class (the blueprint) before you can create an object**





What is Object-Oriented Programming?

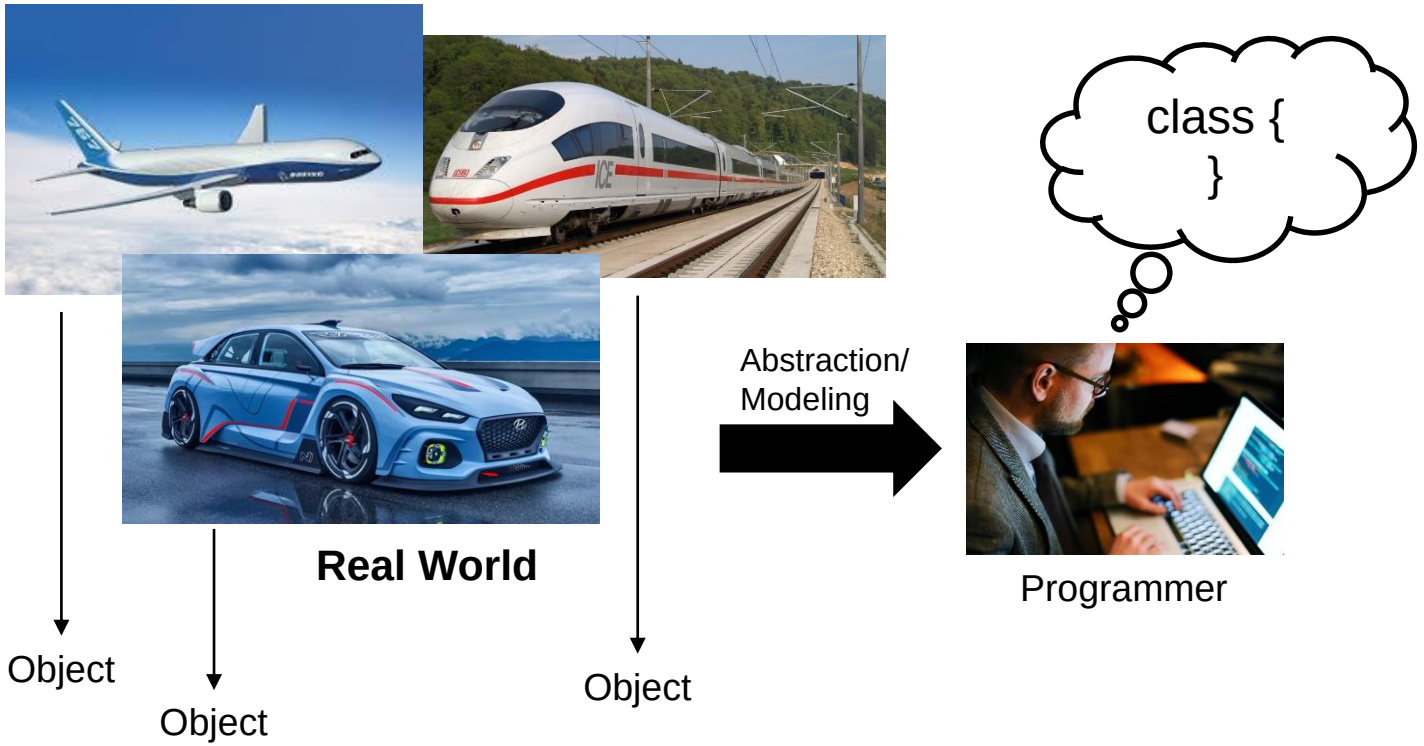
Terminology

- **Class**: Defines what an object of this class knows (state) and does (behavior)
- **Object**: An instance of a class (a concrete thing create from the template / blueprint)
- **Instance Variables**: They represent what an object knows (**the state**)
- **Methods**: They represent what an object can do (**the behavior**)

Difference between a class and object

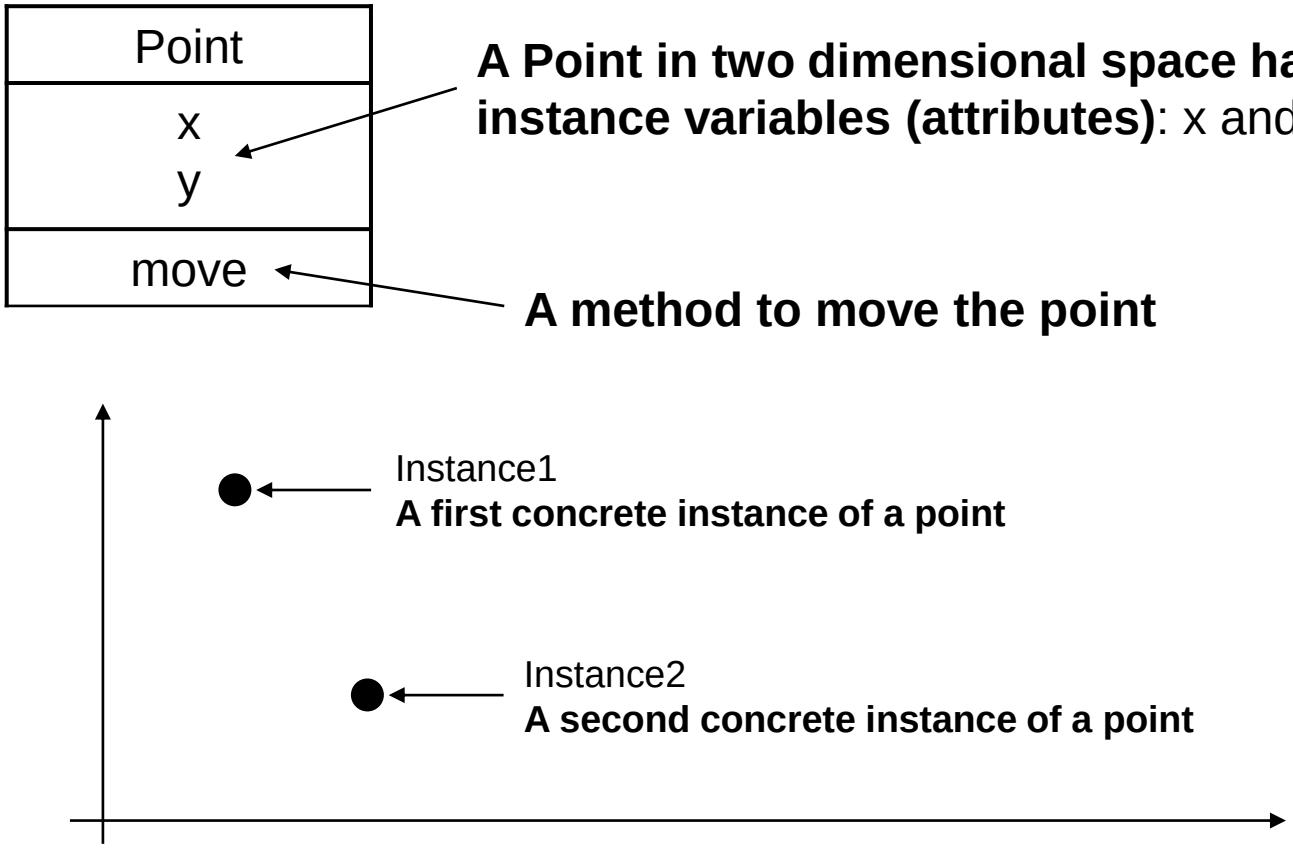
- A **class** is **not an object**!
- A **class** represents a **blueprint for an object**
- It tells us (or the JVM) how to make objects of a particular class
- Each object made of a class has its own states

What is Object-Oriented Programming?

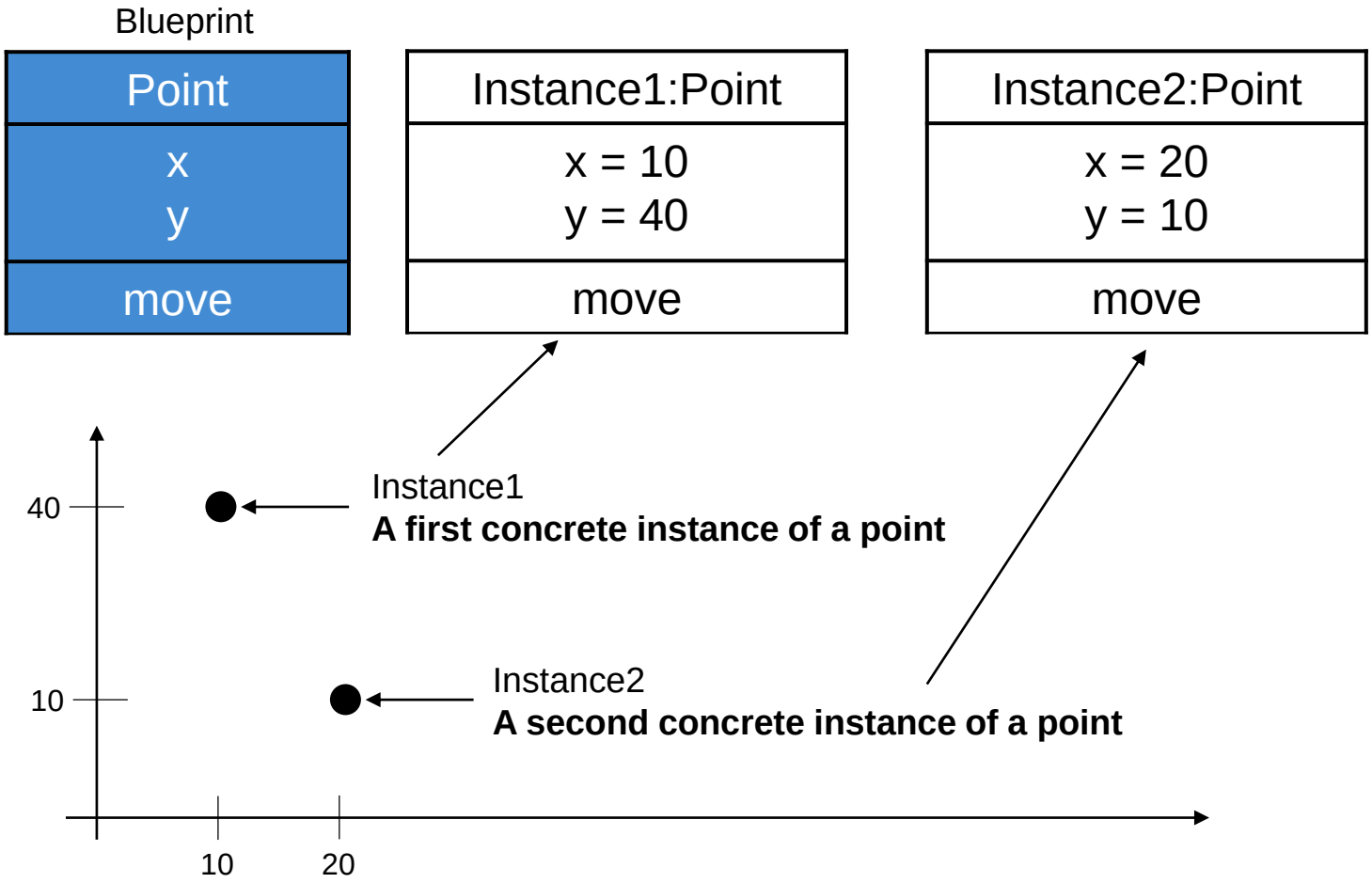


If successful, this medium of expression (the object-oriented way) will be significantly easier, more flexible, and efficient than the alternatives as problems grow larger and more complex.

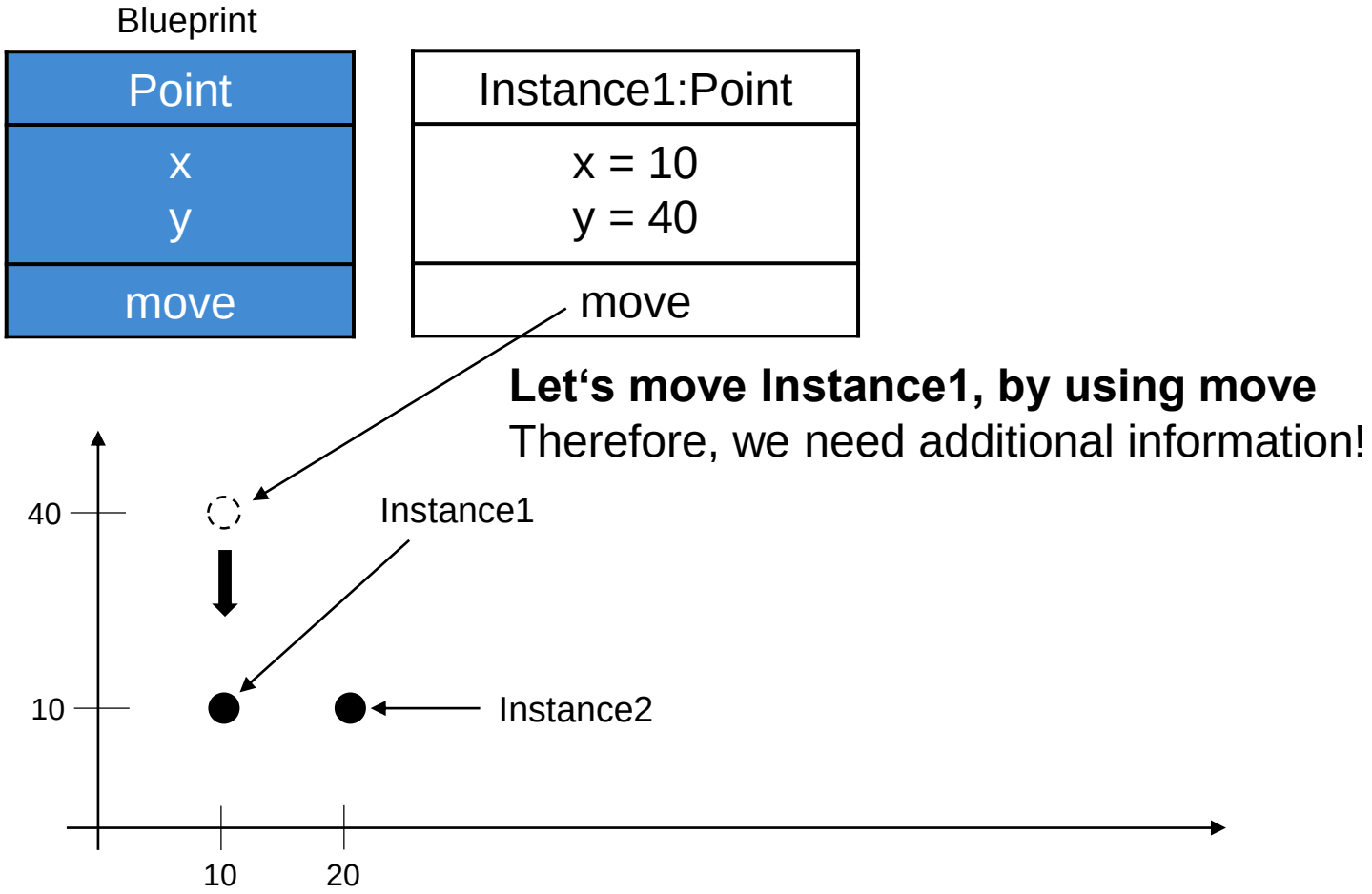
Example: Classes and Objects



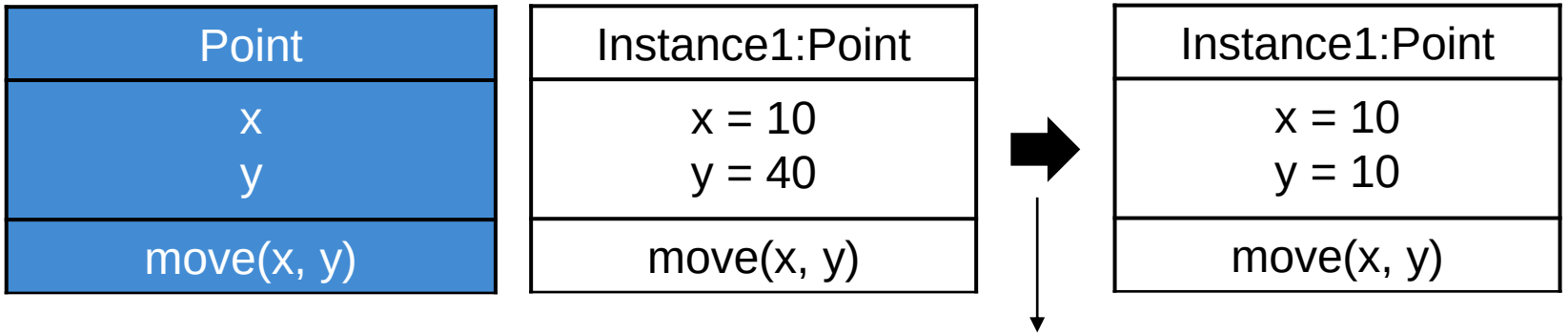
Example: Classes and Objects



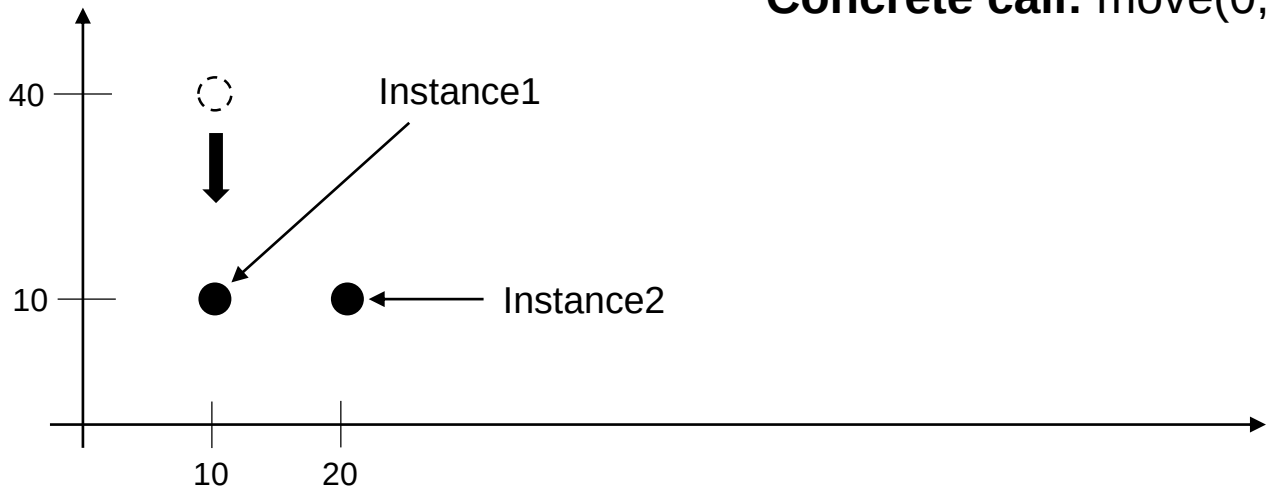
Example: Classes and Objects



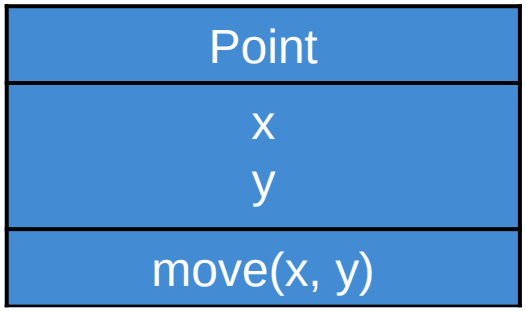
Example: Classes and Objects



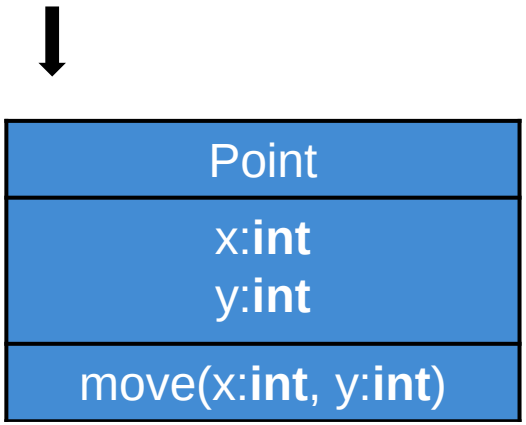
Concrete call: move(0, -30)



Example: Classes and Objects



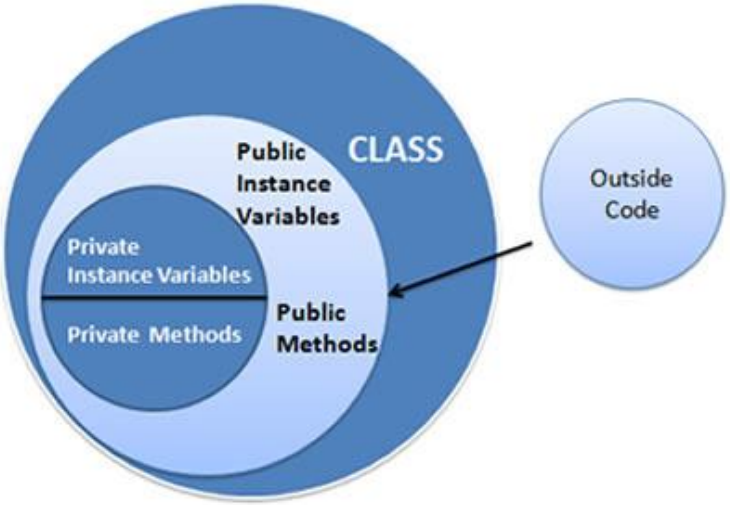
We did not specify the type of the attributes and parameters, yet!

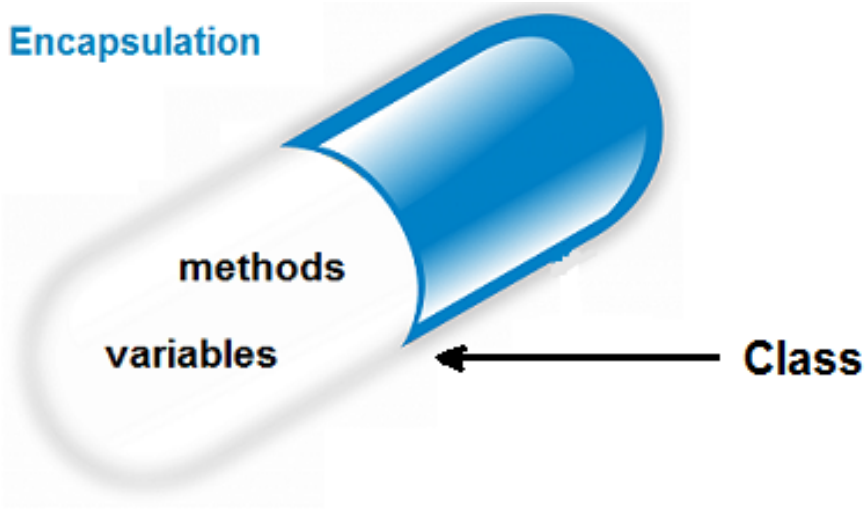


Now we have a blueprint to create hundreds and thousand of points

Core Concept I: Data encapsulation

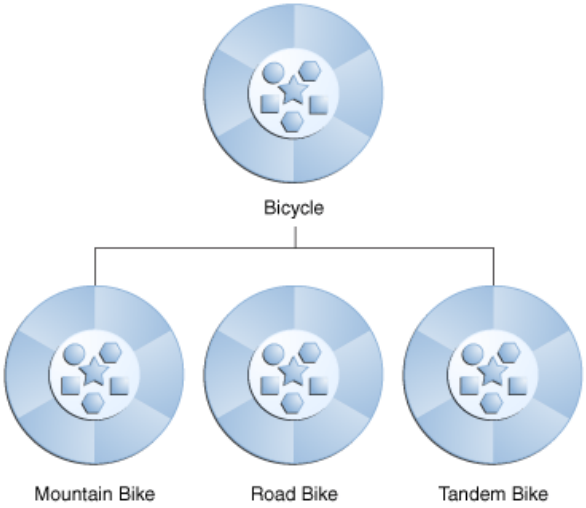
- Encapsulation is the bundling of data with the methods that operate on them
- Remember that in procedural programming this is not the case!
- Also used for hiding the internals of the object from outside view
- Only the object's own methods can operate on it's data
- Protects an object's integrity!





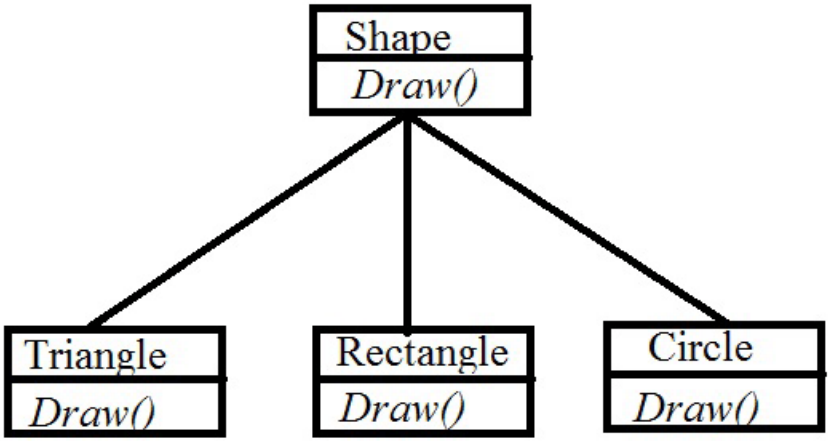
Core Concept II: Inheritance

- Different kinds of objects have a certain amount in common with each other …
- E.g. mountain bikes and tandems all share the characteristics of bicycles
- … yet they each define additional features that make them different
- OOP allows classes to inherit commonly state and behavior from other classes:
- `Bicycle` can be a **superclass** of the **subclasses** `MountainBike` and `Tandem`



Core Concept III: Polymorphism

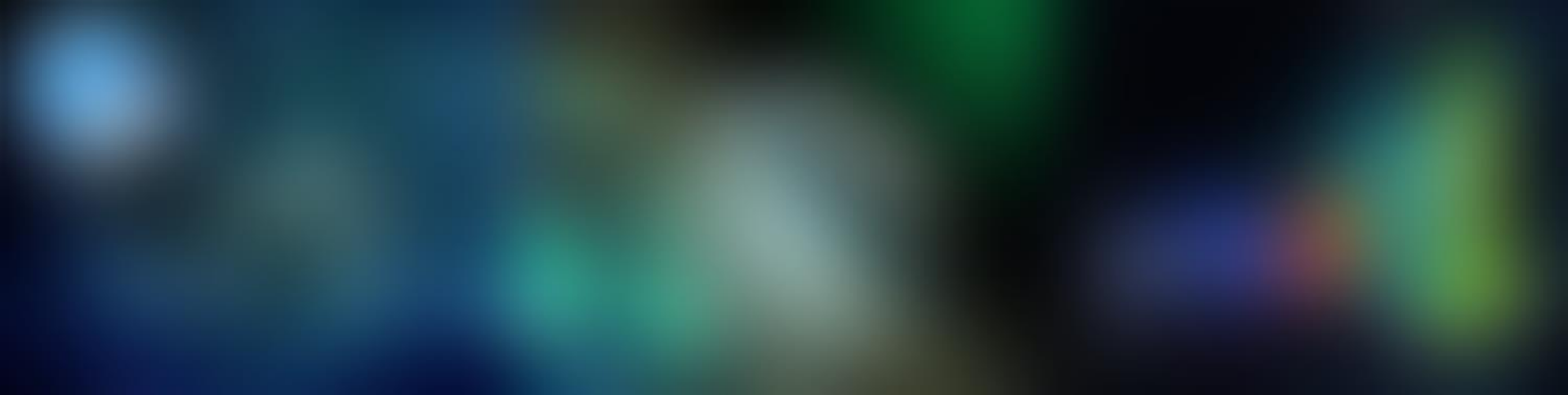
- It's a principle from biology
- An organism can have many different forms or stages
- Poly: many (e.g. polygon); Morph: form (e.g. morphology)
- In OOP it allows to provide a single interface to varying entities of the same type



Core Concept IV: Communication between objects

- Objects can communicate with each other
- … by passing messages!
- One object can get another object to do something
- … through method calls!
- Call a method and pass it some arguments (i.e. messages) or
- Get something from a method trough its returned value.

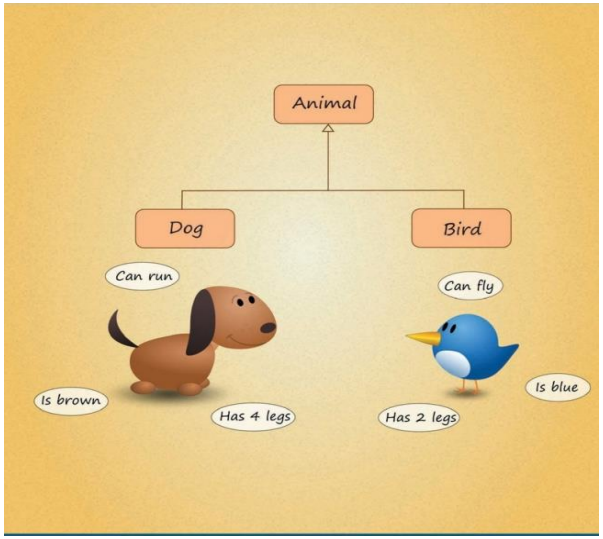
Methods will be covered in detail later this lecture!

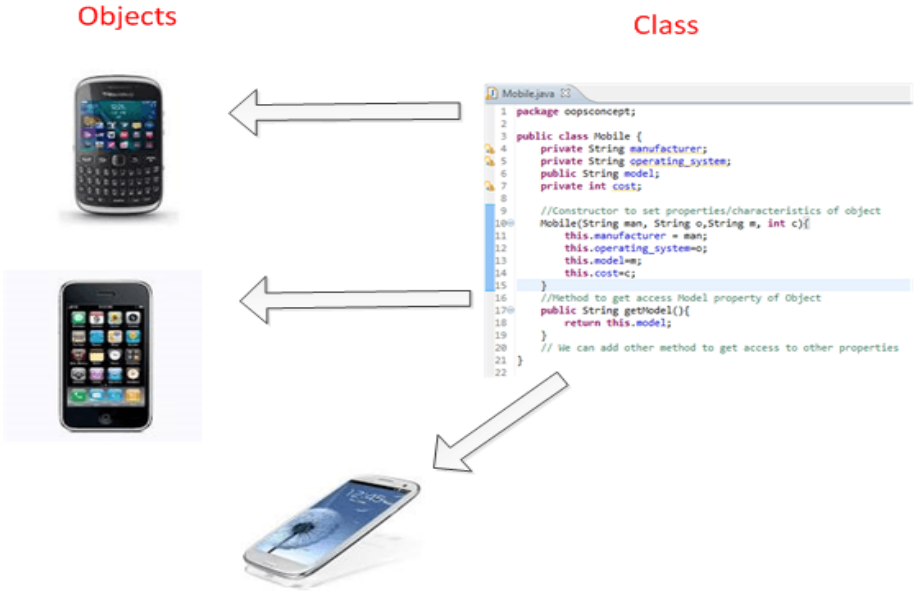


OOP in Java

Introduction

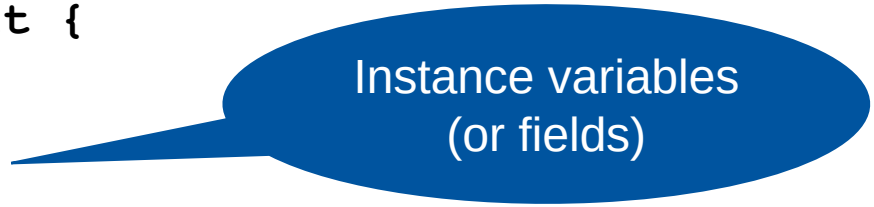
- In lecture 1 we have already met a class definition
- How to create objects from it?
- Java supports **inheritance**, **encapsulation**, **polymorphism** and **message passing**





Creating a class I: A simple example

```
public class Point {

   public int x;
   public int y;

   public void move(int delta_x, int delta_y) {
      x = x + delta_x;
      y = y + delta_y;
   }
}
```



Creating a class II: A simple example

```
public class Application {

   public static void main (String[] args) {

      Point p1 = new Point();

      p1.x = 10;
      p1.y = 40;

      p1.move(0, -30);
   }
}
```

Create a Point object, i.e. create an instance

Set the corrdinates of p1

Call move-method of p1

Creating a class III: A simple example

```
public class Application {

   public static void main (String[] args) {

      Point p1 = new Point();

      p1.x = 10;
      p1.y = 40;

      p1.move(0, -30);
   }
}
```

Data type of p1

Create **new** object of the specified type

The `new` keyword is used for creating instances of classes

Creating a class IV: A simple example

```
public class Application {

   public static void main (String[] args) {

      Point p1 = new Point();

      p1.x = 10;
      p1.y = 40;

      p1.move(0, -30);
   }
}
```

Use the **dot operator** to access public instance variables or methods

Inheritance I

- In Java classes can be derived from other classes …
- Thereby inheriting fields and methods from those classes
- By using the keyword `extends`

Terminology

- **Subclass**: A class derived from an other class
- Subclasses are also know as derived, extended or child classes
- **Superclass**: The class from which the subclass is derived
- Superclasses are also know as base or parent classes

Classes can be derived from classes that are derived from …

Inheritance II

- Every class has one and only one direct superclass
- Except `Object` which has no superclass (see next slide)
- If no other superclass is given every class is implicitly a subclass of `Object`

Inheritance III

- Charming idea: Reuse existing classes with desired functionality
- … by inheriting from them!
- A subclass inherits all members (fields, methods) from it's superclass
- But not its constructors!

For now think of special methods.
We'll cover constructors shortly!

Inheritance IV

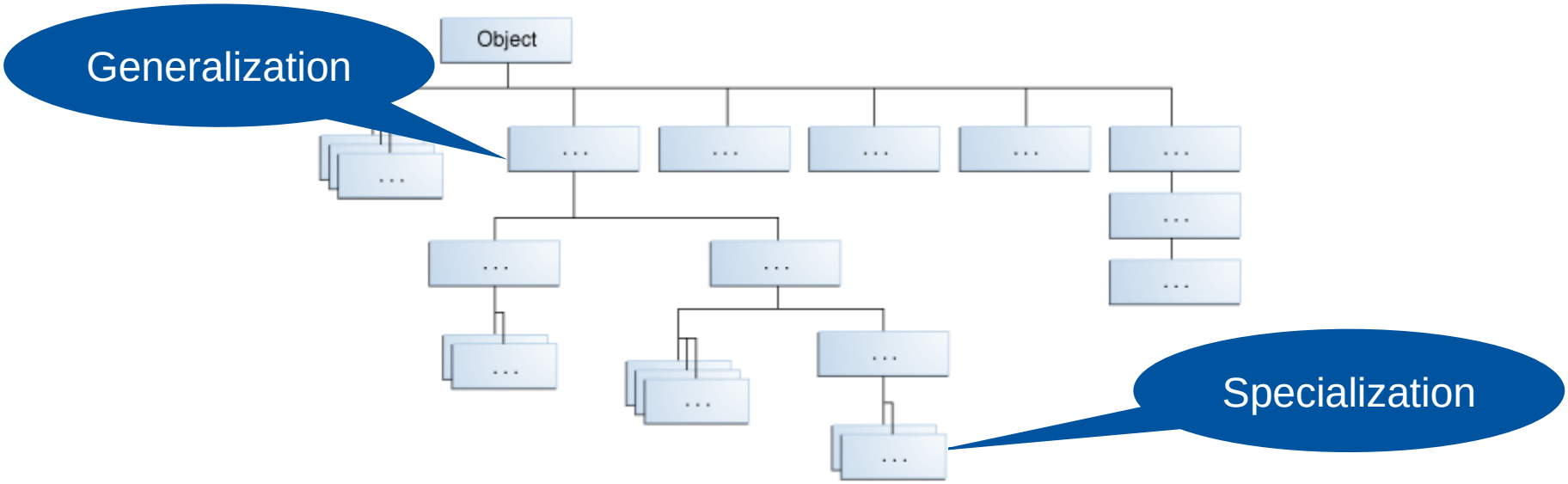
- A subclass inherits all `public` and `protected` members of its parent
- These members can be used in the subclass or replaced or supplemented
- That is you can use fields and methods of the superclass
- You can declare new fields in the subclass (that are not in the superclass)
- Same goes for methods

A subclass does not inherit `private` members of its parent

`public`, `protected` and `private` are topics of data encapsulation (which will be covered shortly)

Inheritance V: The class `object`

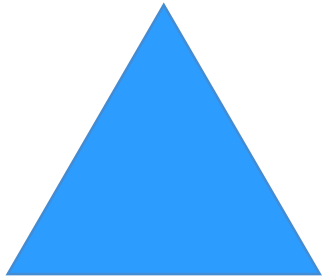
- It's on the top of the Java class hierarchy
- It's the most general of all Java classes
- Defines and implements behavior common to all classes



Inheritance: Example

```
public class Shape {

   public String color;

   public boolean filled;

}
```

This **Rectangle** is a **Shape**
with color “red” and not filled



This **Triangle** is a **Shape**
with color “blue” and filled

Inheritance: Example

`Rectangle` is a subclass of `Shape`

```
public class Rectangle extends Shape {

   public int x1, y1, x2, y2;

   public int calculateArea() {
      return Math.abs(x2 – x1) * Math.abs(y2 – y1);
   }

}
```

It extends its superclass by a method and four attributes

Inheritance: Example

`Triangle` is another subclass of `Shape`

```
public class Triangle extends Shape {

    public int x1, y1, x2, y2, x3, y3;

    public double getSideA() {
        return Math.sqrt(Math.pow(x2 – x1, 2.0) + Math.pow(y2 – y1, 2.0));
    }

    // similar methods to calculate side B and side C
    …

    public double calculateArea() {

        // calculate area by Heron's formula
        double s = 0.5 * (getSideA() + getSideB() + getSideC());
        double area = Math.sqrt(s * (s – getSideA()) * (s – getSideB()) * (s –
            getSideC()));
        return area;
    }
}
```

Inheritance: Example

```
public class ShapeApplication {

   public static void main(String[] args) {

       Rectangle rectangle = new Rectangle();
       Triangle triangle = new Triangle();

       rectangle.color = "red";
       triangle.color = "green";

   }

}
```

Each `Triangle` and `Rectangle` is a `Shape`

Inheritance: Example

```
public class ShapeApplication {

   public static void main(String[] args) {
      Rectangle rectangle = new Rectangle();
      rectangle.color = "red";
      rectangle.x1 = 0;
      rectangle.x2 = 10;
      rectangle.y1 = 0;
      rectangle.y2 = 5;
      System.out.println("Area of rectangle: " +
         rectangle.calculateArea());

   }
}
```

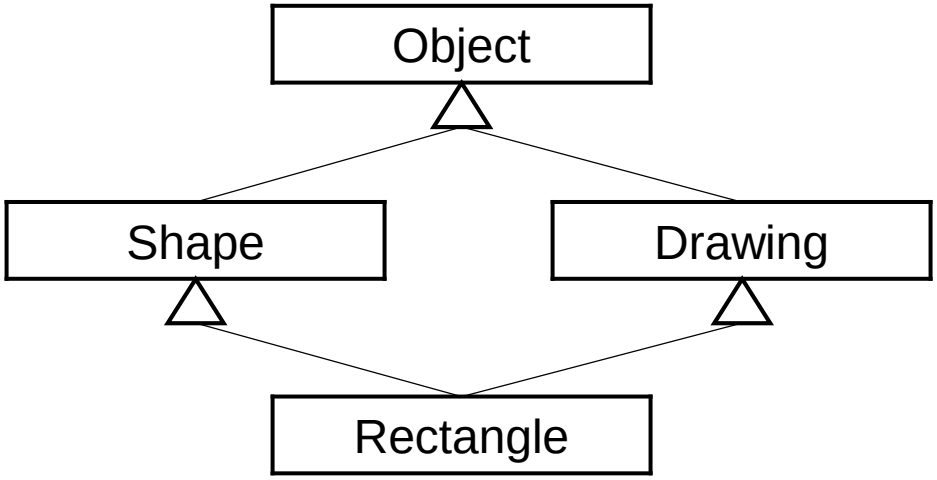
Inheritance: Example

```
public class ShapeApplication {

   public static void main(String[] args) {
      Triangle triangle = new Triangle();
      triangle.color = "green";
      triangle.x1 = 0;
      triangle.x2 = 0;
      triangle.x3 = 10;
      triangle.y1 = 0;
      triangle.y2 = 5;
      triangle.y3 = 0;
      System.out.println("Area of triangle: " +
         triangle.calculateArea());
   }
}
```

Inheritance VI: Inheriting from multiple classes?

```
public class Rectangle extends Shape extends Drawing {
```

That's not allowed in Java! *"Deadly Diamond of Death"*



Data encapsulation in Java

- Remember: Encapsulation wraps data and code together as a single unit and
- The variables of a class will be hidden from other classes and
- Can be accessed only through the methods of their current class
- In Java: Declare the variables of a class as `private`
- And provide `public` methods to modify and view the variable values
- **Again: Encapsulation protects an object's integrity!**

Data encapsulation: Tips on choosing the access level

- Use the most restrictive access level that makes sense for a particular member
- Use `private` unless you have a good reason not to
- Avoid `public` fields except for constants

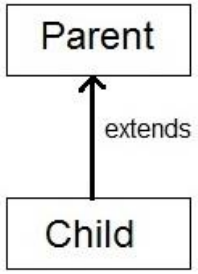
Data encapsulation: Access modifiers

- Java has access modifiers for controlling access to members of a class
- There are two level of access control
- At the top/class level: `public`, or package-private (no explicit modifier)
- At the member level: `public`, `private`, `protected`, or package-private

Modifier	Class	Package	Subclass	World
`public`	Y	Y	Y	Y
`protected`	Y	Y	Y	N
no modifier	Y	Y	N	N
`private`	Y	N	N	N

Polymorphism in Java

- Polymorphism: the reference type can be a superclass of the actual object type!
- **Anything** that extends the declared reference variable type can be assigned …
- … to the reference variable, but **not** the other way round (**Downcasting**!)
- You can have also have polymorphic arguments (and return types) for methods

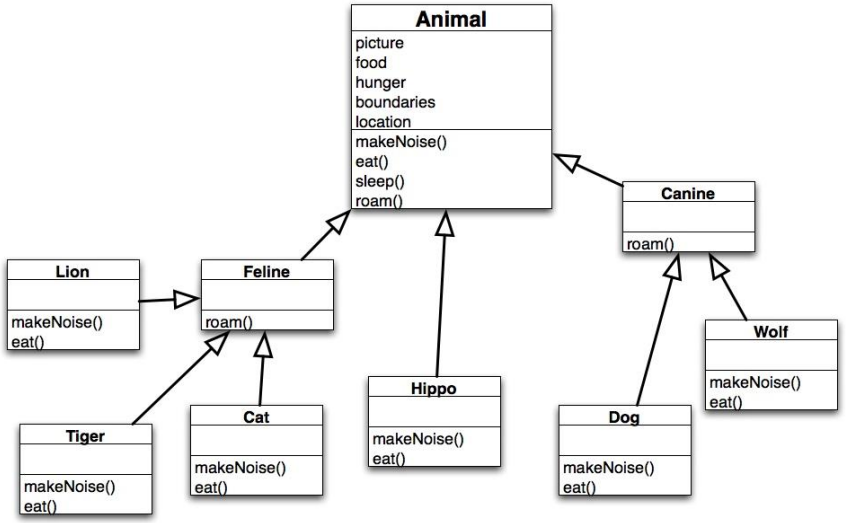



```
Parent p = new Parent( );

Child c = new Child( );

Parent p = new Child( );
```

Upcasting

```
Child c = new Parent( );
```

incompatible type



Polymorphism: Example

```
public class ShapeApplication {

    public static void main(String[] args) {

        Shape shape1 = new Rectangle();
        Shape shape2 = new Triangle();

        shape1.color = "red";
        shape2.color = "green";

    }

}
```

Each `Rectangle` is a `Shape`

Also each `Triangle` is a `Shape`

Hence we can store them in a variables of type `Shape`

Polymorphism: Example

```
public class ShapeApplication {

   public static void main(String[] args) {

        Shape shape1 = new Rectangle();
        Shape shape2 = new Triangle();

        shape1.color = "red";
        shape2.color = "green";

        shape1.calculateArea();
   }

}
```

But we only see the instance variables and methods of a `Shape`

Hence, you cannot call the method `calculateArea`

Polymorphism: Example

```
public class ShapeApplication {

   public static void main(String
      Shape shape1 = new Rectangle();
      Shape shape2 = new Triangle();
      Rectangle rectangle = (Rectangle) shape1;
      rectangle.x1 = 0;
      rectangle.x2 = 10;
      rectangle.y1 = 0;
      rectangle.y2 = 5;
      System.out.println("Area of rectangle: " +
         rectangle.calculateArea());

   }
}
```

Since we know `shape1` contains a `Rectangle`, we can use explicit casts

Polymorphism: Example

```
public class ShapeApplication {

   public static void main(String
      Shape shape1 = new Rectangle();
      Shape shape2 = new Triangle();
      Triangle triangle = (Triangle) shape2;
      triangle.x1 = 0;
      triangle.x2 = 0;
      triangle.x3 = 10;
      triangle.y1 = 0;
      triangle.y2 = 5;
      triangle.y3 = 0;
      System.out.println("Area of triangle: " +
         triangle.calculateArea());
   }
}
```

Same is valid for `shape2`

Polymorphism: Arguments

```
public class ShapeDrawer{

   public void draw(Shape s) {
      // some fancy code to draw shapes
   }

}
```

Any subclass of `Shape` allowed

With polymorphism you can write very flexible code!

The above example will work with any new subclass of `Shape`, e.g. class `Triangle`!

Methods: A Closer Look

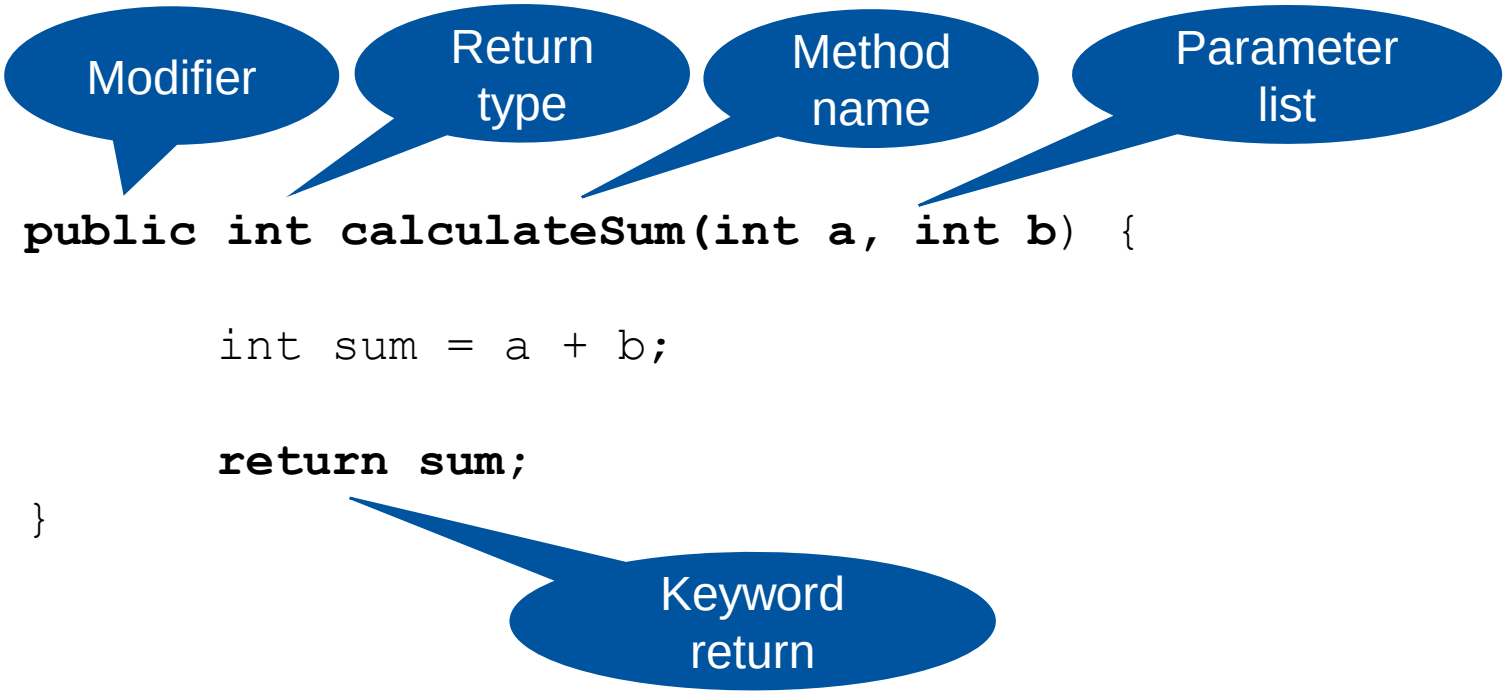
Overview

- **Methods**: They represent what an object does (**the behavior**)
- Methods use instance variables
- They can have **parameters**
- They must have an **return type** (which can be void)

A short example (for a void method with no parameters)

```
public void printHelloAachen() {

   System.out.println("Hello Aachen");

}
```

A more complex example (and terminology)



Method declarations have six components

- **Modifiers**: such as `public`, `private` and others
- **Return type**: data type of the value returned by the method (or `void` if no return)
- **Method names**: see below
- **Parameter list**: comma-delimited list of input parameters, preceded by data type
- **Exception list**: discussed in module 4
- **Method body**: methods code including local variables

Conventions for naming methods

- Names should be a verb in lowercase…
- … or a multi-word name that begins with a verb in lowercase
- Examples: `run, runFast, isEmpty, getFinalData, setEngineSpeed`

Java is always *pass-by-value*!

Method signatures

- The method's name and the parameter types form the *signature*
- Example: `calculateSum(int, int)`
- The return type is not part of the signature

Overloading methods

- Java can distinguish between methods with different signatures
- Methods within a class can have the same name
- But only if they have different parameter lists!
- They are differentiated by the number and type of the arguments passed to them
- You can not declare two methods with same signature but different return type!
- Examples: `draw(String s)`, `draw(int i)`, `draw(int i, double f)`

Excurse: Getters and Setters

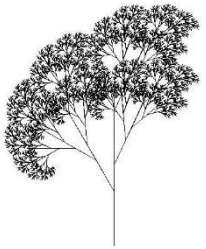
- Are ordinary methods, i.e. they take parameters and return a value
- They let you get and set things, mostly instance variables
- A Getter sends back the value of whatever is supposed to get
- A Setter takes an argument and uses it to set the value of an instance variable

Example

```
public class Shape {
      private String color;
      public String getColor(){
        return color;
      }
      public void setColor(String newColor){
        color = newColor;
      }
}
```

Recursive Calls

- It's a concept which allows a method to call itself!
- Remember the calculation of the factorial? Now we'll use recursion!



$$\text{fact}(n) = \begin{cases} 1 & \text{if } n = 0 \\ n \cdot \text{fact}(n-1) & \text{if } n > 0 \end{cases}$$

Example

```
public int factorial(int n)
{
     if (n == 0)
        return 1;
     else
        return n * factorial(n-1);
}
```

Constructors

Constructors I

- A class contains *constructors* that are invoked to create objects
- They are there to instantiate a class!
- Constructors look similar to methods …
- … except that they use the same name as the class and have no return type!

Example

```
public class Rectangle extends Shape {

    public Rectangle(int aX1, int aY1, int aX2, int aY2){
      x1 = aX1;
      y1 = aY1;
      …
    }
}
```

Constructors II

- Constructors run *before* the object can be assigned to a reference!
- It runs every time you invoke `new`
- If you don't write a constructor for your class the compiler writes one for you …
- … which is called the **default constructor**!

Example

```
public class Rectangle extends Shape {

    public Rectangle(){

    }
}
```

That would be written by the compiler!

Constructors III

- **Constructors are not inherited by the subclass!**
- You can have multiple constructors in your class
- That's called **constructor overloading**!
- Each constructor must have a different parameter list!

Example

```
public class Rectangle {

    public Rectangle(){}
    public Rectangle(int x1, int y1, int x2, int y2){…}
    public Rectangle(int x1, int y1, int x2, int y2, String
       color) {…}
    …
}
```

Abstract Classes

- Some classes should not be instantiated!
- Think of the Shape class … it is just an abstract definition of shapes!
- You can prevent class from being instantiated by marking them `abstract`!
- The opposite to abstract classes are concrete classes!
- **Generally, abstract classes are used for polymorphism (or for inheritance)**

Example

```
public abstract class Shape {
    …
}
```

```
Shape shape = new
Shape();
```
will yield an compiler error!

Abstract Methods

- You can mark methods `abstract`, too!
- **If you declare a method abstract the class must be abstract as well!**
- An abstract method must be overridden in a concrete subclass!
- An abstract method has no body: just end the declaration with a semicolon!

Example

```
public abstract class Shape {

  public abstract double calculateArea();
  public abstract double calculatePerimeter();

}
```

Interfaces

- Sometimes it's necessary for **programmers to agree on a contract** …
- Generally speaking, **interfaces** are such **contracts**!
- In Java an interface is a reference type!
- **An interface defines only abstract methods!**
- An interface is created using the keyword interface!
- A class *implements* an interface using the keyword `implements`!
- A class can **implement multiple interfaces**!

Interfaces: Example

```
public interface Drawable {

     public abstract void draw();
     public abstract void rotate();

}
```

Interfaces: Example

```
public class Rectangle implements Drawable {

  private String color;

  …

  // Implement this method! It's the contract!
  public void draw() {…}

  // Implement this method! It's the contract!
  public void rotate() {…}

}
```

Class vs subclass vs abstract class vs interface

- New class (that doesn't extend anything): if there's nothing to meaningful extend
- Subclass: If a more specific version of an existing class is needed
- Abstract class: If nobody should make objects of the class (e.g. it's a template)
- Interface: For defining a contract that other classes must fulfill!

Thank you very much!

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