Q: Why do Java developers wear glasses?

A: Because they do not C#!

OBJECT-ORIENTED PROGRAMMING

# Subtyping and Inheritance

**Lecture #3**

doc. Ing. Martin Tomášek, PhD.
Department of Computers and Informatics
Faculty of Electrical Engineering and Informatics
Technical University of Košice

2024/2025

## Motivation

- Interesting systems are seldom born into an empty world
  - Almost always, new software expands on previous developments; the best way to create it is by imitation, refinement and combination
  - Traditional design methods largely ignored this aspect of system development
- In object technology it is an essential concern

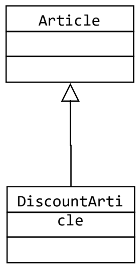
## Motivation

- Reusability
  - To avoid rewriting the same code over and over again, wasting time, introducing inconsistencies and risking errors, we need techniques to capture the striking commonalities that exist within groups of similar structures – all text editors, all tables, all file handlers – while accounting for the many differences that characterize individual cases
- Extendibility
  - The type system in traditional programming languages has the advantage of guaranteeing type consistency at compile time, but prohibits combination of elements of diverse forms even in legitimate cases

## Subtyping

- Remember our Shop Project from the previous lectures
  - Now, let's use new article type with percentage discount and changed or new behavior
- `DiscountArticle` is a **subtype** of `Article`
- `Article` is a **supertype** of `DiscountArticle`

`DiscountArticle ≤ Article`



## Subtype substitution

- If *B* is a subtype of *A* ($B \leq A$), everywhere the code expects an *A*, a *B* can be used instead
- Examples:

```
Article a = b;
```

**What is `b`?**

`b` must be a subtype of `Article`
(Note: *A* is subtype of *A*)

```
Article a = new Article();
Article a = new DiscountArticle();
```

~~`DiscountArticle a = new Article();`~~

## Implementation issues

- Subtyping
  - Allow one type to be used where another type is expected
- Inheritance
  - Reuse implementation of the supertype to implement a subtype

## Inheritance

- To implement a subtype, it is often useful to use the implementation of its supertype
- This is also called **subclassing**
- In Java (similar in other languages):

Both subtyping and inheritance

```
class B extends A
```

B is a subtype of A

B inherits from A

Just subtyping

```
class C implements D
```

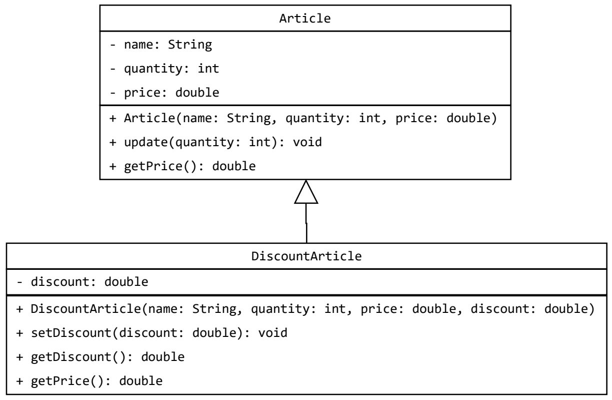
C is a subtype of D

## Inheritance example: Analysis

- Remember our Shop Project from the previous lectures
  - We have `Shop` and `Article` classes defined to implement articles selling process
- Now, let's use new article type with percentage discount and changed or new behavior
  - New discount article will use the same characteristics and behavior as normal articles
  - There are also new characteristics and extended behavior for the discount article
    - Percentage discount value
    - Article price calculation must apply the discount

## Inheritance example: Design

- By inheritance we can create new classes based on existing classes
  - New class `DiscountArticle` inherits all characteristics and behaviors of class `Article` and also defines some new


Article
- name: String
- quantity: int
- price: double
+ Article(name: String, quantity: int, price: double)
+ update(quantity: int): void
+ getPrice(): double
DiscountArticle
- discount: double
+ DiscountArticle(name: String, quantity: int, price: double, discount: double)
+ setDiscount(discount: double): void
+ getDiscount(): double
+ getPrice(): double

## Terminology remarks

- `Article`
  - Main class, parent class, ancestor, superclass
- `DiscountArticle`
  - Inherited class, derived class, child (daughter) class, descendant, subclass
- Inheritance is also called **subclassing**

## Using inheritance

- We can define new classes easily, we do not need to rewrite whole behavior
- We can use new object-oriented notion of types – **polymorphism**
  - What type is object `butter` of in our example?
    - The reference to the object `butter` is of type `Article`, but the object itself is from class `DiscountArticle`
    - Object `butter` can be used both as `Article` and `DiscountArticle` types
  - Objects from subclasses can be always used as objects from their superclasses

## Using inheritance

- Derived classes can **define new** characteristics and behaviors
  - New characteristics and behaviors can be used only with derived class
  - For example in our example we cannot call `butter.getDiscount()`, because the reference `butter` is of type `Article` and `getDiscount()` is behavior of `DiscountArticle`
  - We must take care what types do we use (superclass or subclass?) with the object
- Derived classes can **rewrite (override) existing** behaviors
  - Overridden behaviors are always used according the creation class of the object
  - For example in our example we can call `butter.getPrice()`, even if the reference to the `butter` object is of type `Article`, the behavior from class `DiscountArticle` is used
  - Note: Object-oriented languages (Java, C++, C# etc.) have various possibilities to rewrite functions in subclasses

## Binding

- At a certain point, the method invocation is **bound** to the method definition, that is, a commitment is made to execute certain code
- Though binding often occurs at compile-time, the binding of a method invocation to its definition cannot be made till run-time for a polymorphic reference
- Consider

```
obj.doSomthing();
```

- If `obj` is polymorphic, it can refer to different types of objects at different times, thus calling a different definition of `doSomething()` each time it is invoked

## Late or dynamic binding

- For polymorphic references, the method definition that is used depends on the object that is being referred by the reference variable at that moment
- This binding decision cannot be made until run-time and is thus called **late** or **dynamic binding**
- Though it is less efficient for bindings to occur at run-time rather than compile-time, it is considered to be an acceptable overhead given the flexibility of a polymorphic reference
- There are two ways to create a polymorphic reference
  - using inheritance
  - using an interface

## Overridden method dispatch

- `DiscountArticle` is a subtype of `Article`
- If `DiscountArticle` **overrides** method `getPrice()` of `Article` which method should be called?

```
Article a = new Article();
DiscountArticle da = new DiscountArticle();
double p;
p = a.getPrice();
p = da.getPrice();
a = da;
p = a.getPrice();
```

Calls class `Article`'s `getPrice()` method

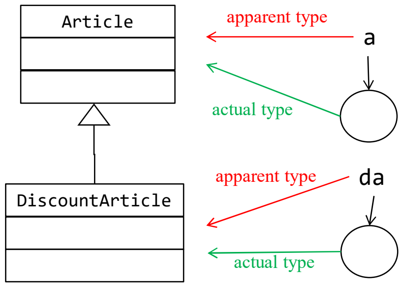
Calls class `DiscountArticle`'s `getPrice()` method

Calls class `DiscountArticle`'s `getPrice()` method

## Dynamic dispatch

- Search for the method up the type hierarchy, starting from the actual (dynamic) type of the object

```
Article a = new Article();
DiscountArticle da = new DiscountArticle();
double p;
p = a.getPrice();
p = da.getPrice();
```

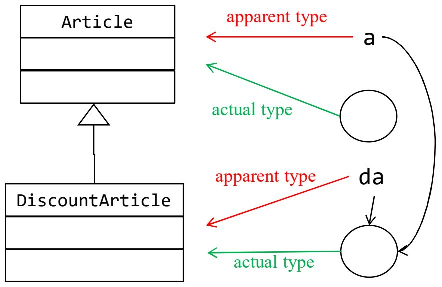


## Dynamic dispatch

- Search for the method up the type hierarchy, starting from the actual (dynamic) type of the object

```
Article a = new Article();
DiscountArticle da = new DiscountArticle();
double p;
p = a.getPrice();
p = da.getPrice();
a = da;
p = a.getPrice();
```

Now apparent type of a is `Article` and actual type of a is `DiscountArticle`



## Apparent and actual types

- **Apparent types** are associated with declarations
  - They never change
- **Actual types** are associated with object
  - They are always a subtype of the apparent type
- Compiler does type checking using **apparent type**
- During run-time the method dispatch is using **actual type**

## Information hiding in inheritance

- All characteristics and behaviors are inherited to new class
- We can use accessibility modificators to control the **direct accessibility** of inherited properties
  - **`public`** – properties are accessible from outer classes and all derived classes
  - **`private`** – properties are accessible only in the class it is defined
  - **`protected`** – properties are not accessible from outer classes, but still accessible from derived classes

## Constructing object of derived class

- At the beginning of each constructor of subclass **the default constructor of superclass is called**
  - In our example when creating object of `DiscountArticle` class the default `Article()` constructor within `DiscountArticle()` constructor is called
  - When we want to call other than default constructor we can use **`super`** keyword to call different overloaded version of constructor, as we can see in our example

```
public DiscountArticle(String name, int quantity, double price, double discount) {
  super(name, quantity, price);
  this.discount = discount;
}
```

## Using the **`super`** keyword

- Accessing overridden superclass members
  - If your method overrides one of its superclass's methods, you can invoke the overridden method through the use of the keyword `super`

```
@Override
public double getPrice() {
  return super.getPrice() * (1.0 - this.discount);
}
```

- Subclass constructor
  - As mentioned before when we want to invoke superclass's constructor

```
public DiscountArticle(String name, int quantity, double price, double discount) {
  super(name, quantity, price);
  this.discount = discount;
}
```

## Methods of reuse

- Another way of functionality reuse is **objects composition**
- One of the main object-oriented principle is to **favor composition over inheritance**
- Both composition and inheritance support
  - Reusability
  - Extendibility

## Composition

- Method of reuse in which new functionality is obtained by creating an object **composed of** other objects
- The new functionality is obtained by delegating functionality to one of the objects being composed
- Sometimes called **aggregation** or **containment**, although some authors give special meanings to these terms
  - **Aggregation** – when one object owns or is responsible for another object and both objects have identical lifetimes or when one object has a collection of objects that can exist on their own
  - **Containment** – a special kind of composition in which the contained object is hidden from other objects and access to the contained object is only via the container object

## Implementation of composition

- Composition can be
  - By reference
  - By value
- C++ allows composition by value or by reference
- But in Java or C# all we have are object references

## Advantages/disadvantages of composition

- Advantages
  - Contained objects are accessed by the containing class solely through their interfaces
  - “Black-box” reuse, since internal details of contained objects are **not** visible
  - Good encapsulation
  - Fewer implementation dependencies
  - Each class is focused on just one task
  - The composition can be defined dynamically at run-time through objects acquiring references to other objects of the same type
- Disadvantages
  - Resulting systems tend to have more objects
  - Interfaces must be carefully defined in order to use many different objects as composition blocks

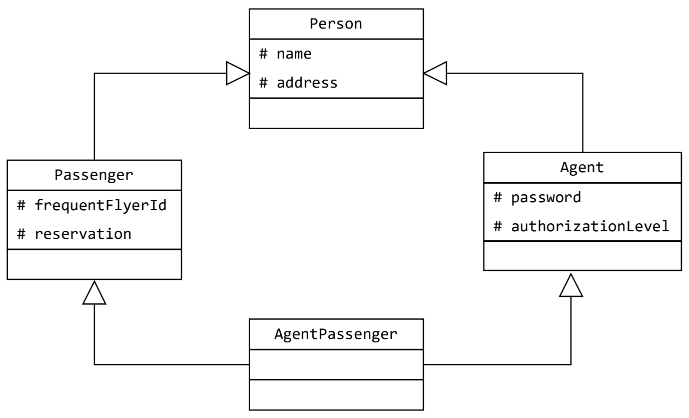
## Advantages/disadvantages of inheritance

- Advantages
  - New implementation is easy, since most of it is inherited
  - Easy to modify or extend the implementation being reused
- Disadvantages
  - Breaks encapsulation, since it exposes a subclass to implementation details of its superclass
  - “White-box” reuse, since internal details of superclasses are often visible to subclasses
  - Subclasses may have to be changed if the implementation of the superclass changes
  - Implementations inherited from superclasses can not be changed at runtime

## Coad’s rules

- Use inheritance only when all of the following criteria are satisfied
  - A subclass expresses **is a special kind of** and not **is a role played by a**
  - An instance of a subclass never needs to become an object of another class
  - A subclass extends, rather than overrides or nullifies, the responsibilities of its superclass
  - A subclass does not extend the capabilities of what is merely a utility class
  - For a class in the actual problem domain, the subclass specializes a role, transaction or device

## Inheritance vs. composition: Example 1



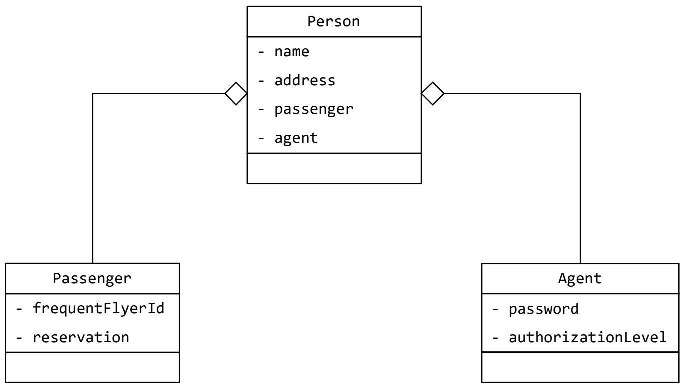
## Inheritance vs. composition: Example 1

- “Is a special kind of” not “is a role played by a”
  - **Fail**. A passenger is a role a person plays. So is an agent.
- Never needs to transmute
  - **Fail**. An instance of a subclass of `Person` could change from `Passenger` to `Agent` to `AgentPassenger` over time
- Extends rather than overrides or nullifies
  - **Pass**.
- Does not extend a utility class
  - **Pass**.
- Within the problem domain, specializes a role, transaction or device
  - **Fail**. A person is not a role, transaction or device.

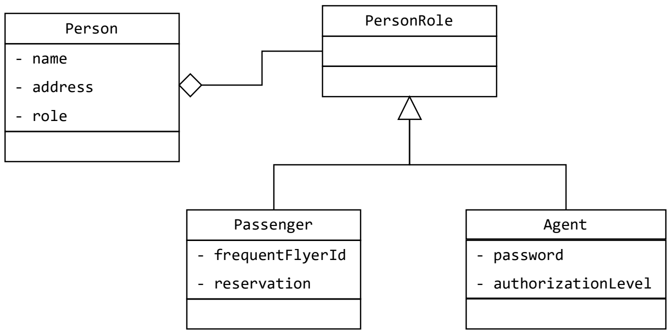
- **Inheritance does not fit here!**

## Inheritance vs. composition: Example 2

- No inheritance at all



## Inheritance vs. composition: Example 3



## Inheritance vs. composition: Example 3

- "Is a special kind of" not "is a role played by a"
  - **Pass**. Passenger and agent are special kinds of person roles.
- Never needs to transmute
  - **Pass**. A `Passenger` object stays a `Passenger` object; the same is true for an `Agent` object.
- Extends rather than overrides or nullifies
  - **Pass**.
- Does not extend a utility class
  - **Pass**.
- Within the Problem Domain, specializes a role, transaction or device
  - **Pass**. A person role is a type of role.

- **Inheritance ok here!**

## Inheritance vs. composition summary

- Both composition and inheritance are important methods of reuse
- Inheritance was overused in the early days of object-oriented development
- Over time we have learned that designs can be made more reusable and simpler by favoring composition
- Of course, the available set of composable classes can be enlarged using inheritance
- So composition and inheritance work together
- But our fundamental principle is
  - **Favor composition over inheritance**