Introduction to Java (cs2514)

Lecture 9: Abstract Classes

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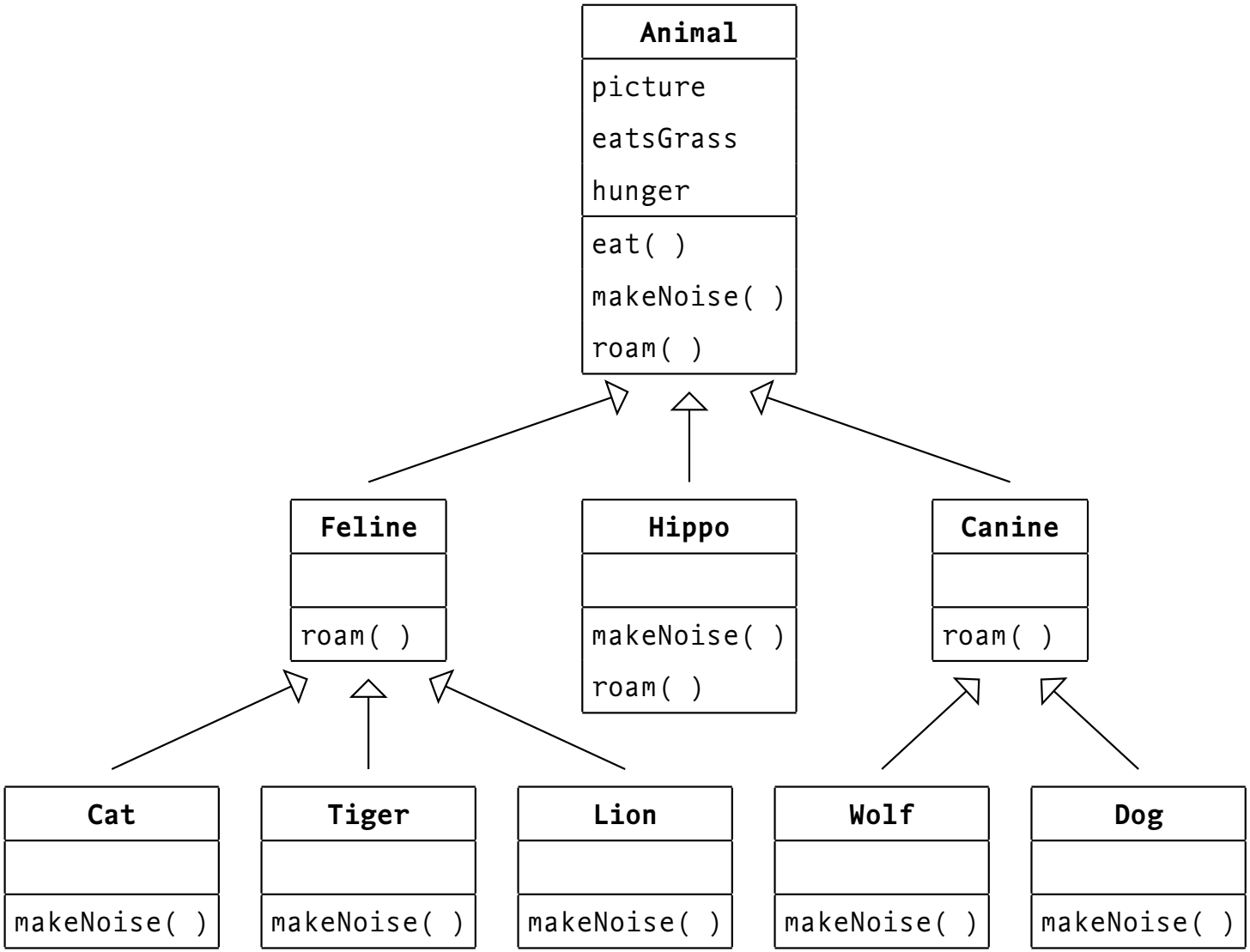
Outline

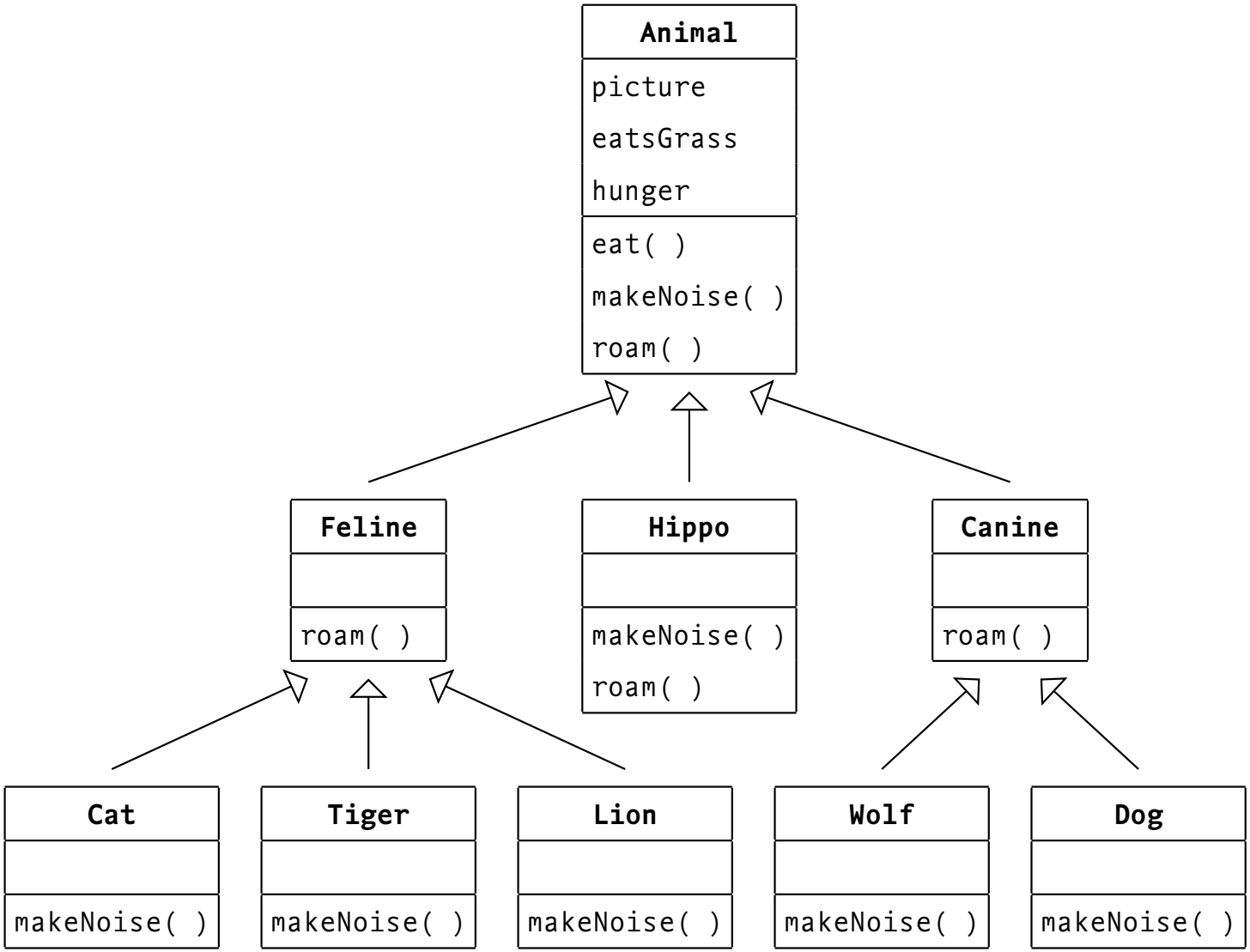
- Learn how to create abstract classes, which cannot be extended.
- Decide class membership with `instanceof`.
- Learn how to override some common methods:
  - `toString( );`
  - `equals( );`
- *Control* inheritance with `final` classes and methods.
- We study *multiple inheritance:*
  - We start with a case study;
  - We see advantages and disadvanteges of different designs;
  - We end up with a disasterous design complication;
  - We learn how overcome the complication.
- We study the *strategy design pattern:*
  - Defines a class of related algorithms;
  - Encapsulates them;
  - Makes them interchangable.
- We learn three disign principles:
  - Encapsulate what varies;
  - Program to an interface;
  - Favour composition over inheritance.

Abstract Classes



Abstract Classes

```
Hippo hippo = new Hippo( )
```



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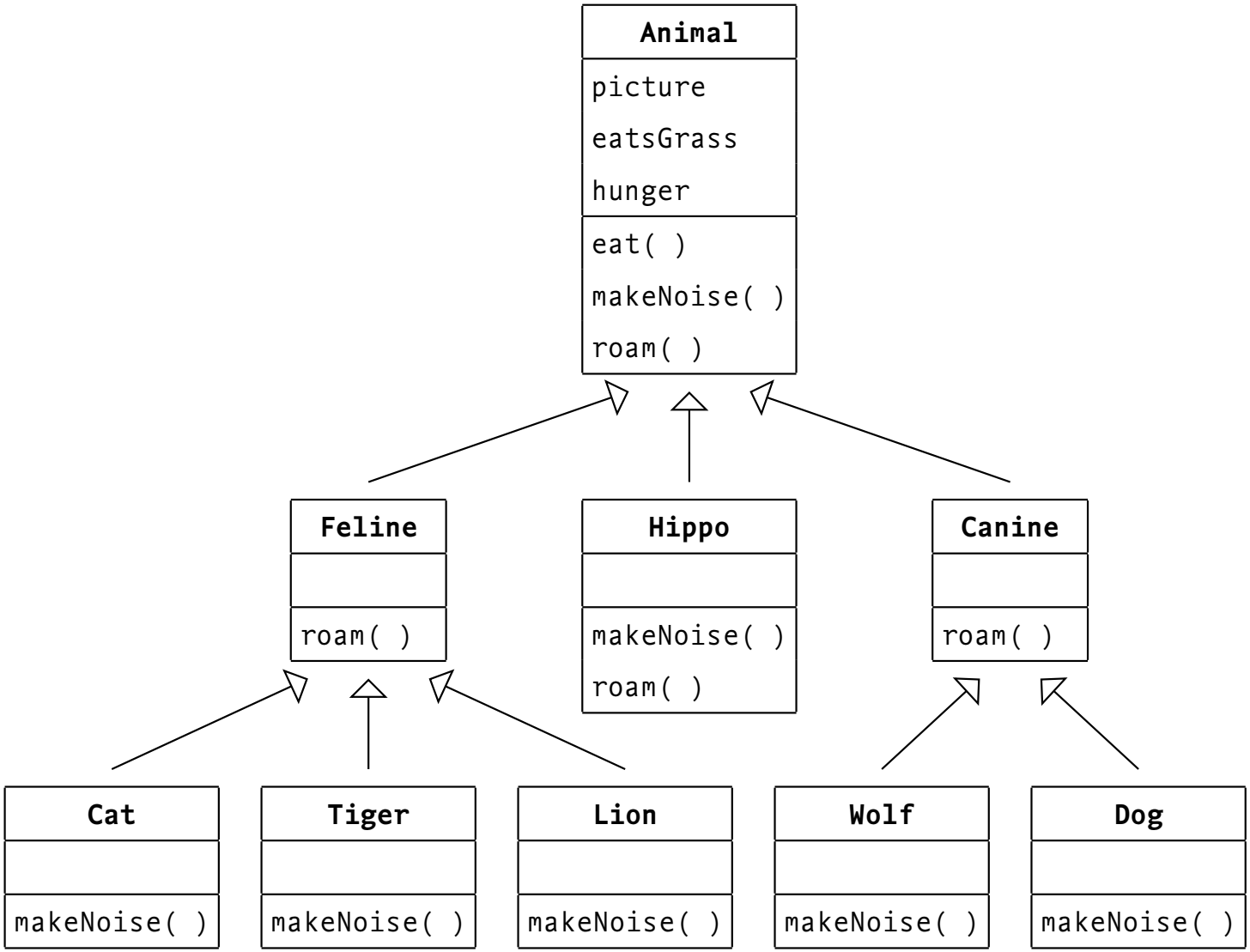
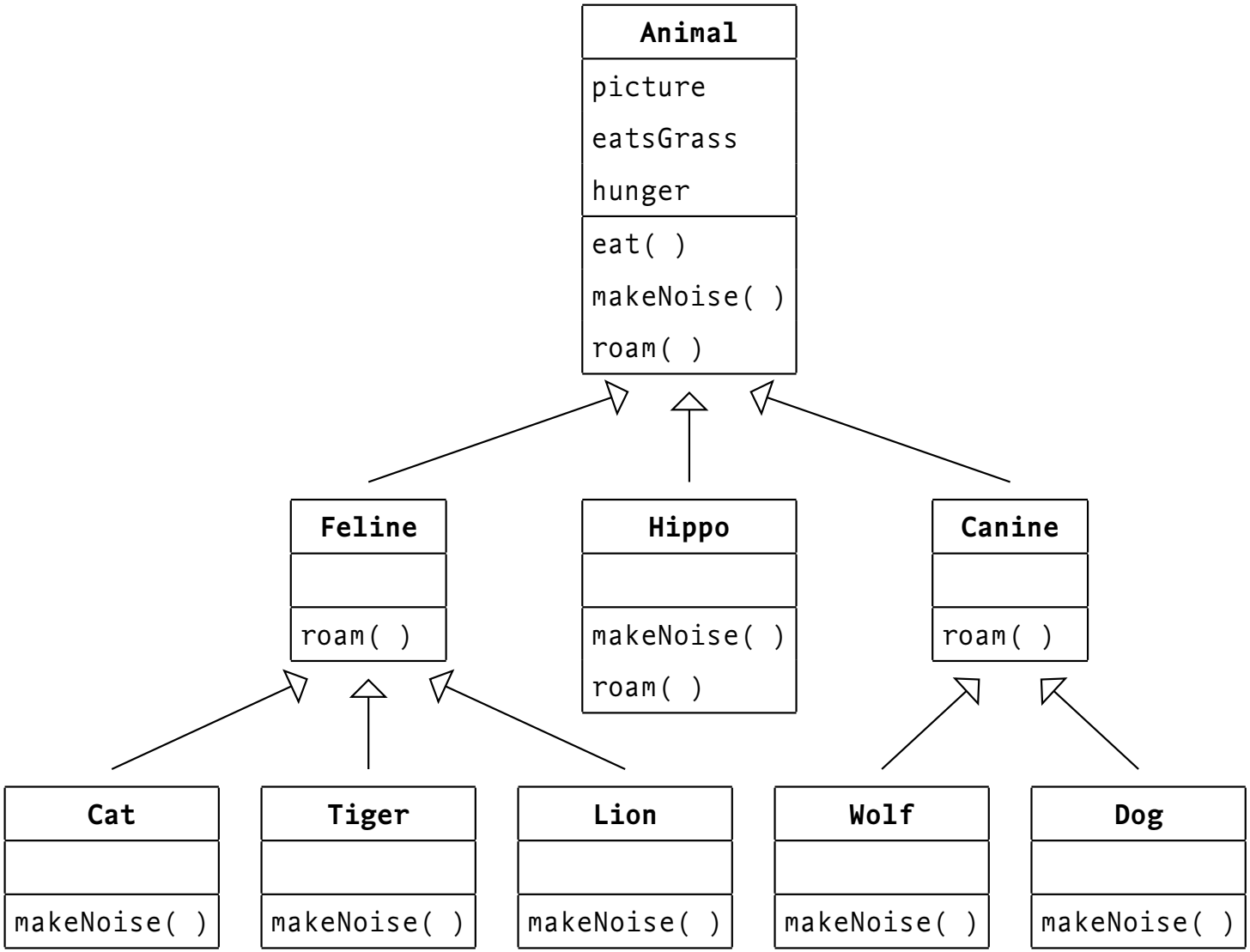


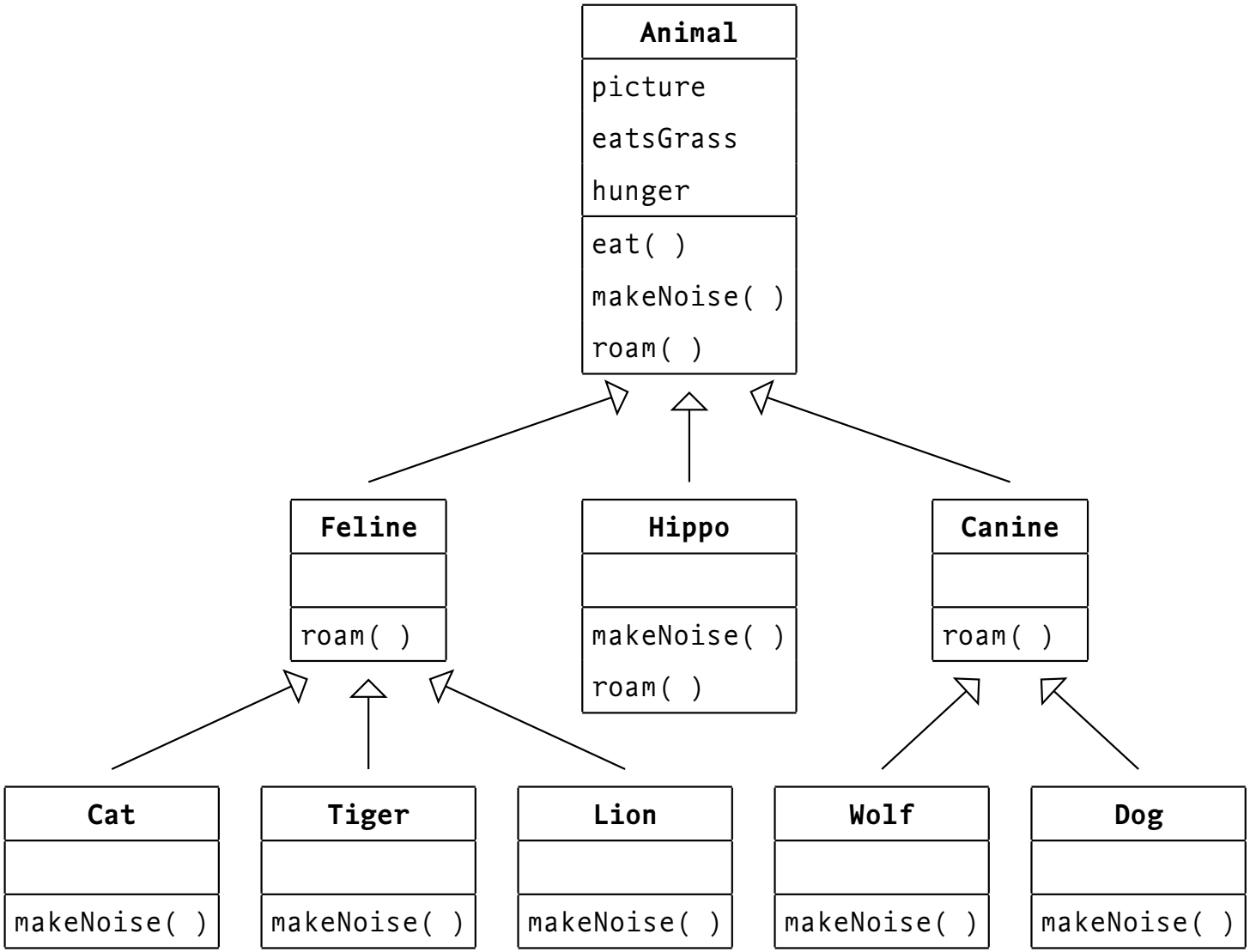
Abstract Classes

```
Cat cat = new Cat( )
```



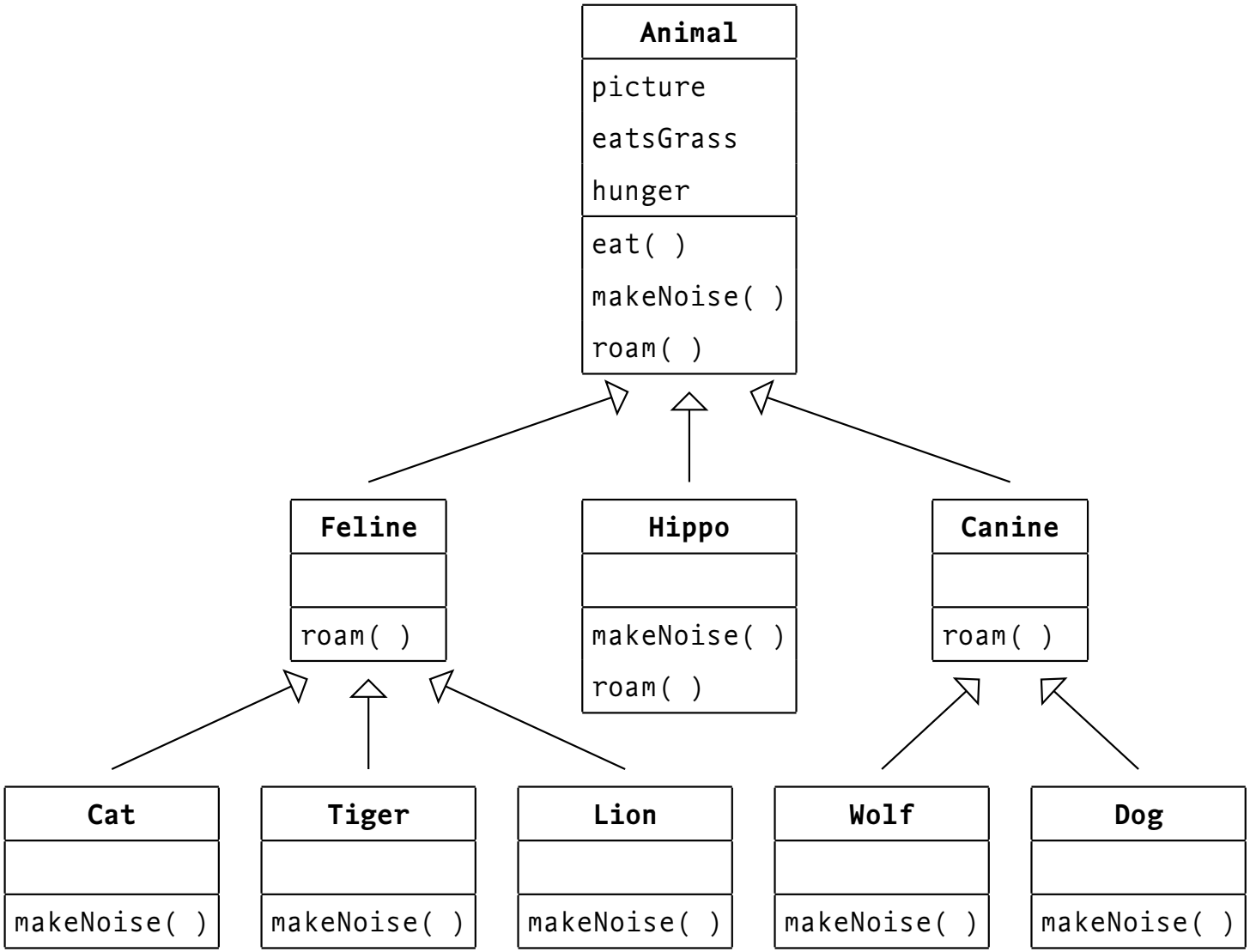
Abstract Classes

```
Cat cat = new Cat( );
```
√



Abstract Classes

```
Animal animal = new Cat( )
```



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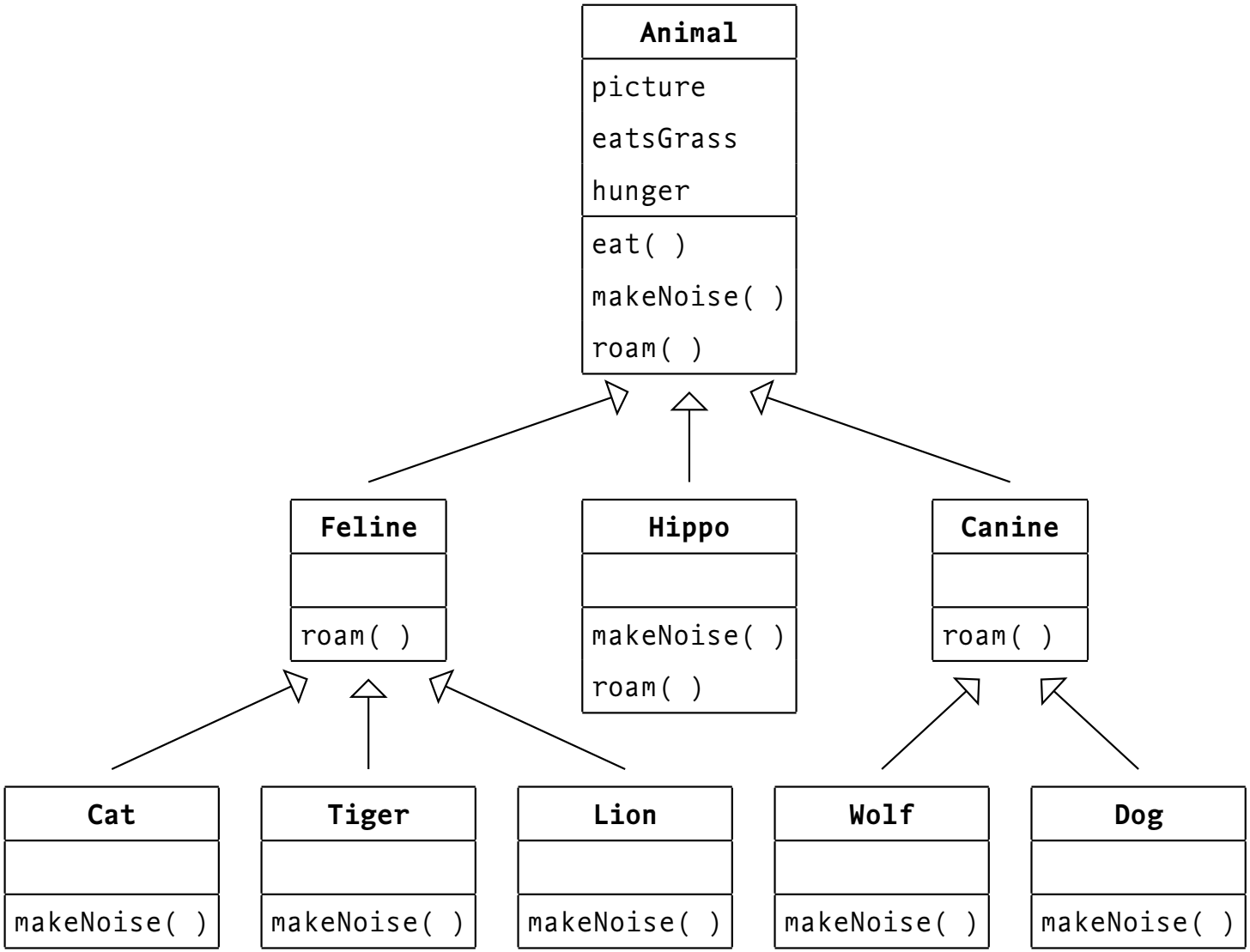
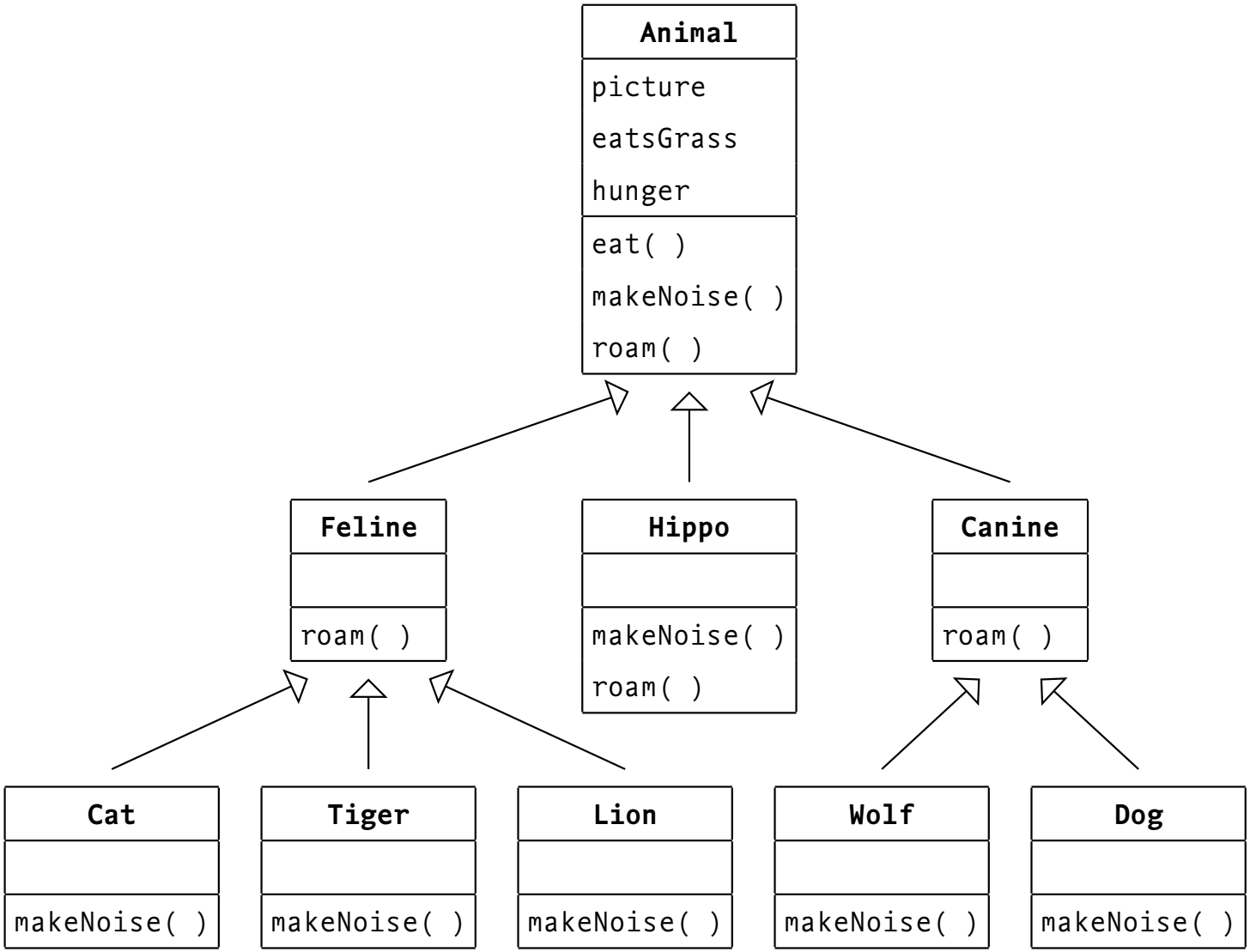


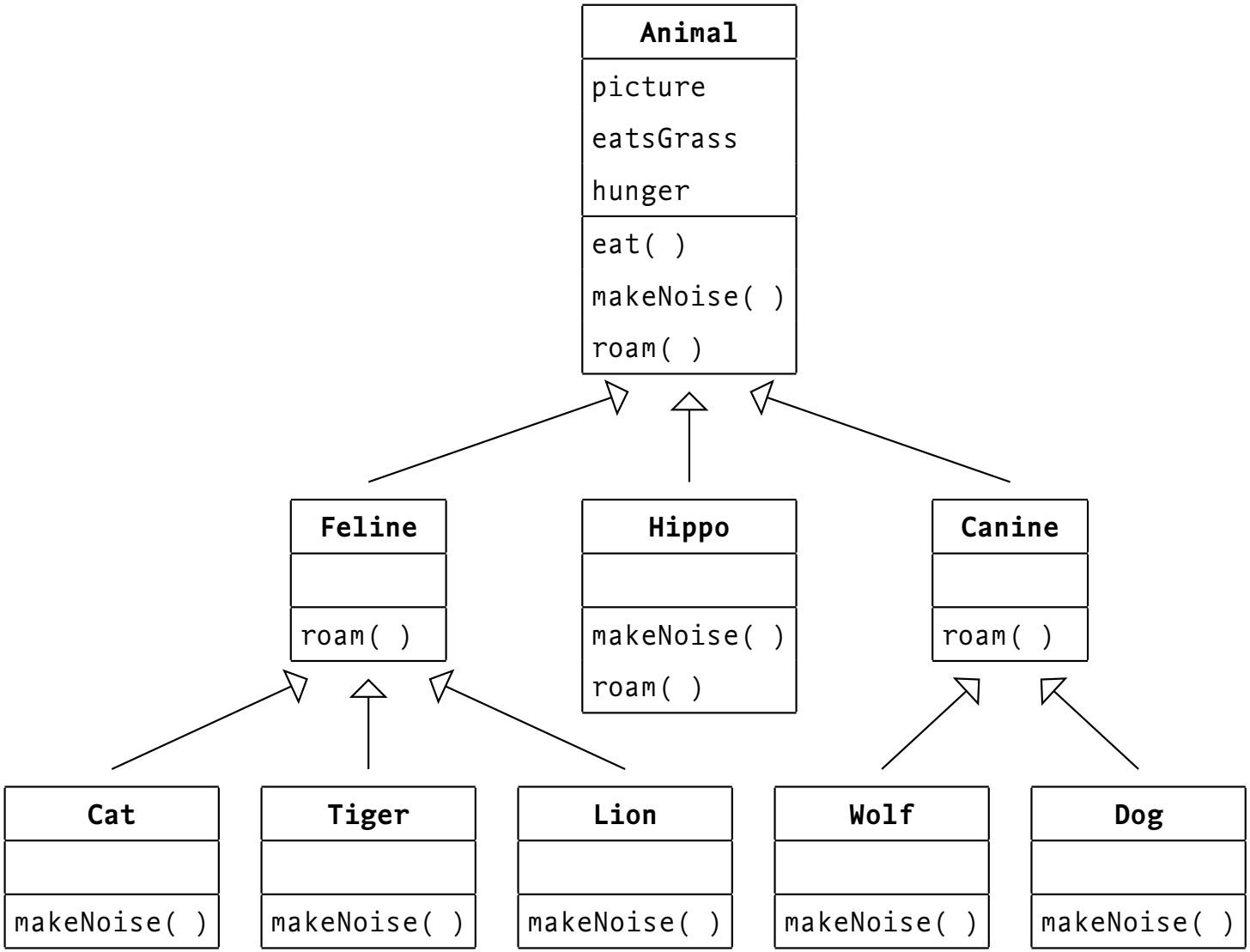
Abstract Classes

```
Animal animal = new Animal( )
```



Abstract Classes

`Animal animal = new Animal( )???`



Why do we Need the `Animal` Class?

- We need it for inheritance, so we can:
  - Share common code, and
  - Define a common API for `Animals`.
- We need it for polymorphism, so we can:
  - Write code that will still work if we add subclasses.

Some Classes Should Never be Instantiated

- We never wanted the `Animal` class to be instantiated.
- We want `Cat` and `Dog` objects, but not `Animal` objects.
- The spell `abstract` prevents classes from being instantiated.

Java

```
public abstract class Animal {
    ...
}
```

- Now `javac` won't let you instantiate abstract classes:

Don't Try This at Home

```
Animal animal = new Animal( );
```

Subclasses can be Abstract Too

Java

```
public abstract class Canine extends Animal {
    ...
}
```

Abstract and Concrete Classes

- A class is *abstract* if it's defined with the keyword `abstract`.
- Otherwise it is *concrete*.

Abstract and Concrete Classes (Continued)

- You can still use abstract polymorphic reference variables.

Java

```
Dog dog = new Dog( );
Cat cat = new Cat( );
Animal animal = dog;
animal = cat;
```

- But, you can only instantiate concrete classes.

Java

```
Cat cat = new Cat( );
Animal dog = new Dog( );
```

- Instantiating an abstract base class *array* is also allowed.

Java

```
Animal[] animals = new Animal[ 3 ];
```

Abstract Methods

- `Java` also has *abstract methods*.
  - They are defined in abstract classes,
  - They are defined with the keyword `abstract`, and
  - They have no body.

Java

```
public abstract void roam( );
```

Why Have Abstract Methods

- Abstract classes *must* be *extended*.
- Abstract methods *must* be *overridden*.
  - They define the nature of the common protocol.
  - They don't require a default implementation.
  - Saves you from forgetting to implement proper behaviour.

Why Have Abstract Methods

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- Abstract methods *must* be *overridden*.
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  - Saves you from forgetting to implement proper behaviour. √

Implementing Abstract Methods

- Abstract methods have no body.
  - They only occur in abstract classes.
  - They have no default behaviour.
- Each concrete subclass needs the behaviour for its API.
- Therefore, you *have to* implement the abstract method.
- You implement an abstract method by providing a body.
  - This is called *overriding* the method.
  - This may be done in any class on the shortest path from concrete class to the abstract class that defines the abstract method.
  - So, implementing in abstract subclasses is allowed.
  - Of course, a method may be overridden, and overridden, ...

How does this Work?

Implementing the Method

Java

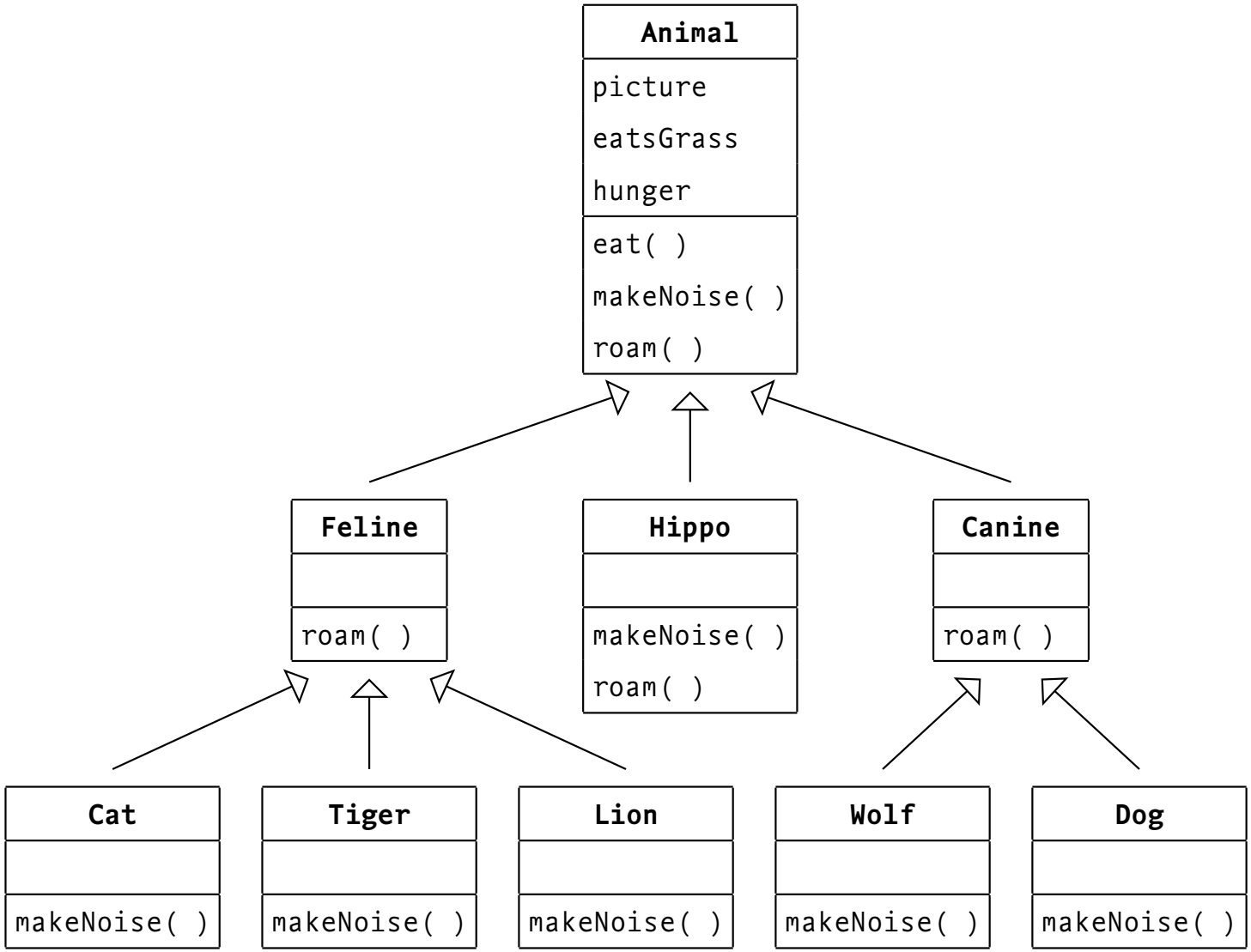
```
public abstract class Animal {
    public abstract void makeNoise( );
}
```

Java

```
public class Dog extends Animal {
    @Override
    public void makeNoise( ) { ... }
}
```

How does this Work?

Implementing the Method for all Relevant Classes



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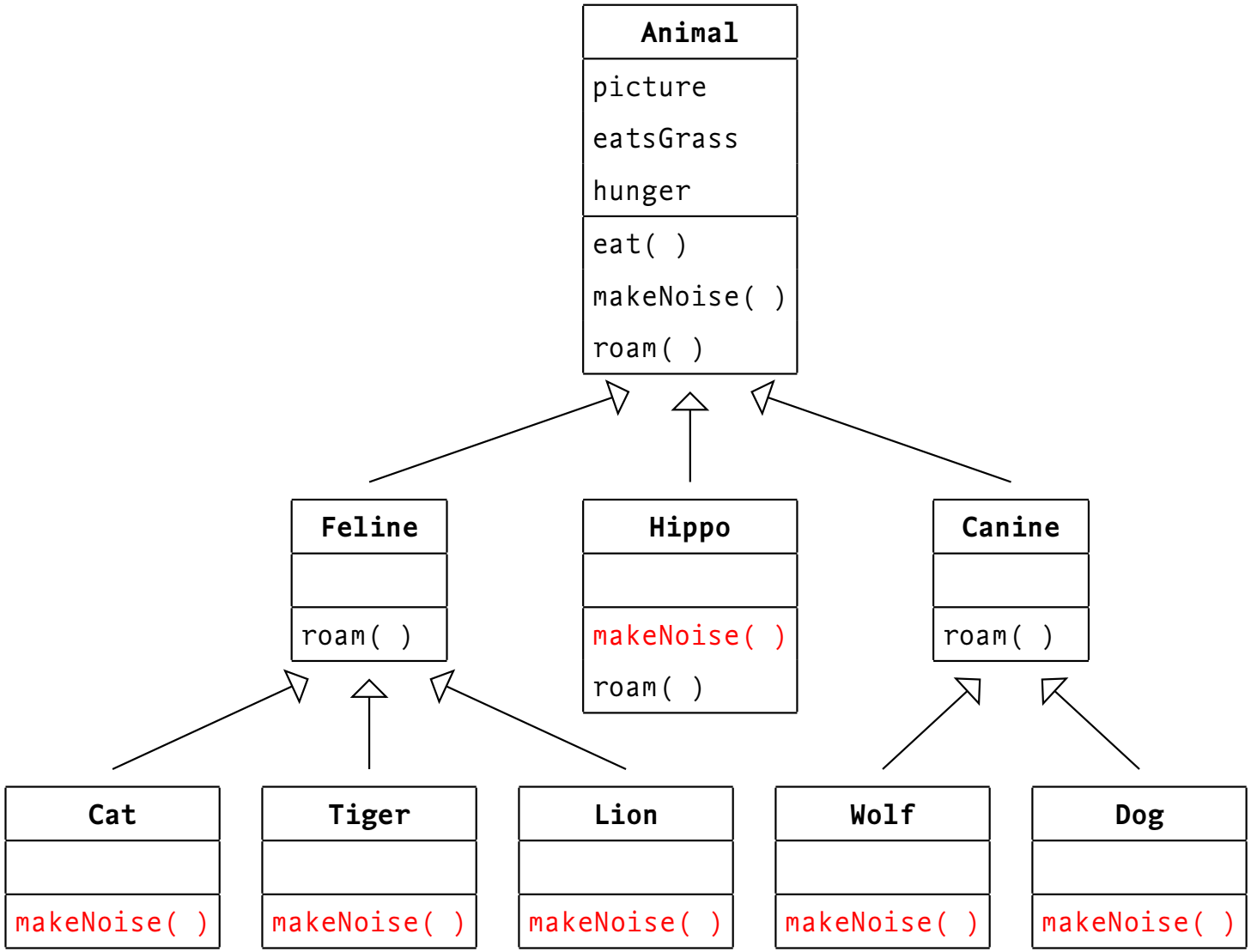
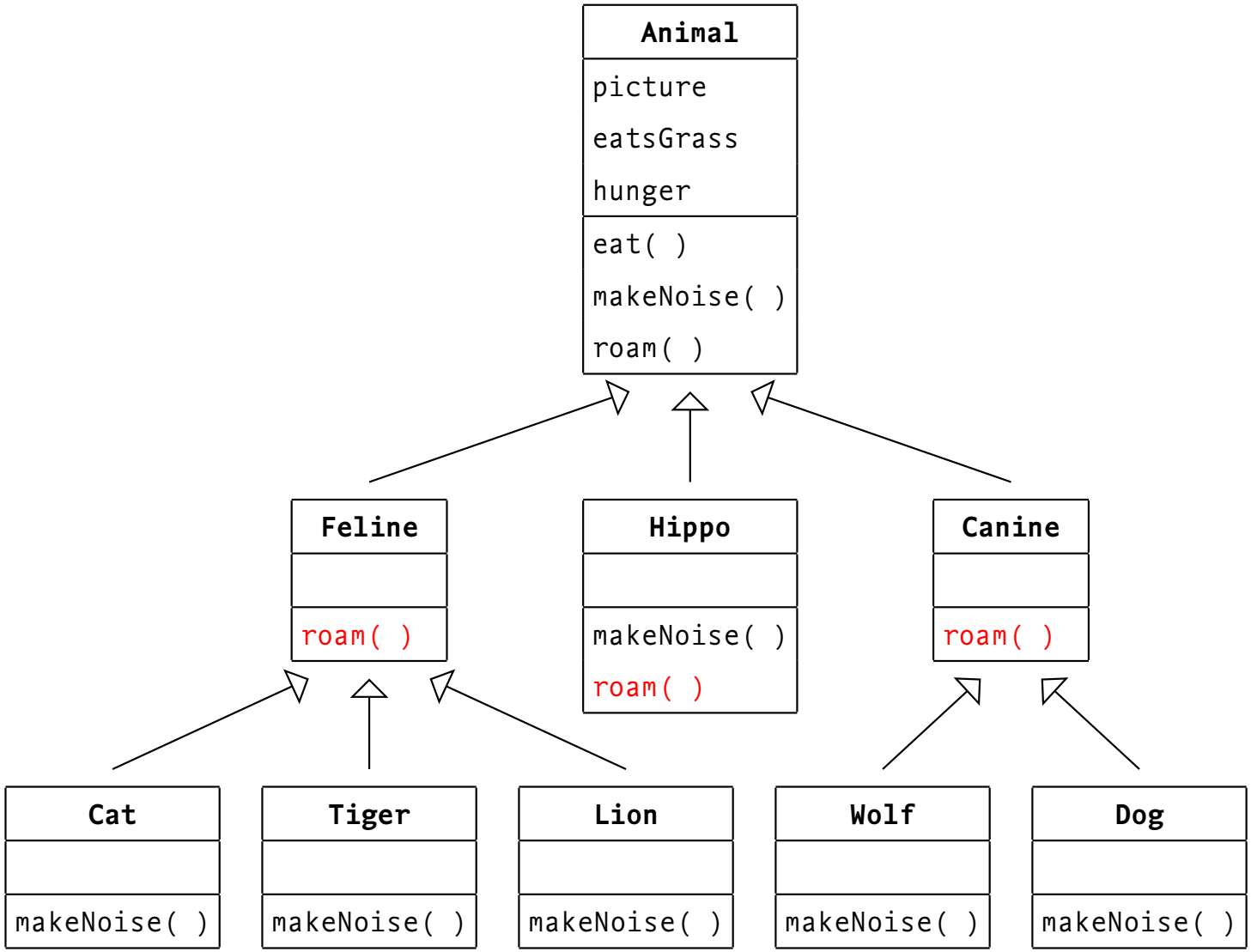


How does this Work?

Implementing the Method for all Relevant Classes



The Barber Paradox?

- A barber shaves people who don't shave themselves.
- There's a small town with only one barber.

The Barber Paradox?

- A barber shaves people who don't shave themselves.
- There's a small town with only one barber.
- Who shaves the barber?

Deciding Class Membership

- Sometimes you need to decide class/interface membership.
- For example, when a polymorphic variable's type is too loose.

Java

```
public class Person {
    public static void main( String[] args ) {
        final Barber barber = Barber.orderBarber( );
        final Person person = new Person( );
        person.shave( );
        barber.shave( );
    }

    public void shave( ) {
        final Person person = this;
        if (/* person is a Barber */) {
            final Barber barber = (Barber)person;
            barber.shaveYourself( );
        } else {
            final Barber barber = Barber.orderBarber( );
            barber.shave( person );
        }
    }
}
```

- More important applications a few slides further on.

Deciding Class Membership

- Sometimes you need to decide class/interface membership.
- For example, when a polymorphic variable's type is too loose.

Java

```
public class Barber extends Person {
    private Barber( ) { }

    public static Barber orderBarber( ) {
        return new Barber( );
    }

    public void shaveYourself( ) {
        System.out.println( "Shaving myself" );
    }

    public void shave( final Person person ) {
        System.out.println( "Shaving person" );
    }
}
```

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Deciding Class Membership

- Sometimes you need to decide class/interface membership.
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    }

    public void shave( ) {
        final Person person = this;
        if (person instanceof Barber) {
            final Barber barber = (Barber)person;
            barber.shaveYourself( );
        } else {
            final Barber barber = Barber.orderBarber( );
            barber.shave( person );
        }
    }
}
```

- More important applications a few slides further on.

Deciding Subclass Membership

- The spell `reference instanceof Clazz` tests for class membership of `Clazz`.
- It returns:
  - `true` if `reference` references an instance of `Clazz`;
  - `true` if `reference` references an instance of a subclass of `Clazz`;
  - `false` otherwise (including when `reference == null`).
- The test also works for interfaces.

Java

```
final String bomb = "blast";

if (bomb instanceof Comparable) {
    System.out.println( bomb );
}
```

Overriding `toString( )`

- The `Object` class defines `public String toString( );`
  - It's an instance method.
- It should return a "meaningful" representation of its instance.
- Arguably most classes should override the method.
- It's especially useful when testing.

How?

Depends on the Class

Java

```
public class Person {
    private final String firstName;
    private final String surname;

    ...

    @Override
    public String toString( ) {
        return firstName + " " + surname;
    }
}
```

How?

Depends on the Class

Java

```
public class Die {
    private final Random generator; // not printed
    private int faceValue;
    ...

    @Override
    public String toString( ) {
        return Integer.toString( faceValue );
    }
}
```

How?

Depends on the Class

Java

```
public class DataBaseConnection {
    private final Database db;
    private final long id;
    private final Port port;
    ...

    @Override
    public String toString( ) {
        return "DatabaseConnection[ id = " + id
                                + ", db = " + db
                                + ", port = " + port
                                + ... // all attributes
                                + " ]";
    }
}
```

How?

Depends on the Class

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```
public class DataBaseConnection {
    private final Database db;
    private final long id;
    private final Port port;
    ...

    @Override
    public String toString( ) {
        return "DatabaseConnection[ id = " + id
                                + ", db = " + db // ????
                                + ", port = " + port
                                + ... // all attributes
                                + " ]";
    }
}
```

How?

Depends on the Class

Java

```
public interface Testable {
    public String getTestOutput( );
}

public class Port implements Testable { ... }
public class Database implements Testable { ... }

public class DataBaseConnection implements Testable {
    private final Database db;
    private final long id;
    private final Port port;
    ...

    // Better!
    @Override
    public String getTestOutput( ) {
        return "DatabaseConnection[ id = " + id
                                + ", db = " + db.getTestOutput( )
                                + ", port = " + port.getTestOutput( )
                                + ... // all attributes
                                + " ]"l
    }
}
```

Overriding `equals( )`

- `public boolean equals( Object object ):`
  - Also defined in the `Object` class.
- Method is supposed to test for deep equality.
- Easy if you know the base class of `object`:

Java

```
public class Person {
    private final String firstName;
    private final String surname;

    ...

    @Override
    public boolean equals( Object object ) {
        final Person that = (Person)object;
        return this.firstName.equals( that.firstName )
                  && this.surname.equals( that.surname );
    }
}
```

Overriding `equals( )`

- `public boolean equals( Object object ):`
  - Also defined in the `Object` class.
- Method is supposed to test for deep equality.
- Easy if you know the base class of `object`:

Java

```
public class Person {
    private final String firstName;
    private final String surname;

    ...

    @Override
    public boolean equals( Object object ) {
        final Person that = (Person)object;
        return this.firstName.equals( that.firstName )
                  && this.surname.equals( that.surname );
    }
}
```

- But what if you don't know the base class?

Overriding equals( )

If You're Not Sure About Base Class

Java

```
public class Person {
    private final String firstName;
    private final String surname;

    ...

    @Override
    public boolean equals( Object object ) {
        final boolean result;

        if (object instanceof Person) {
            final Person that = (Person)object;
            result = this.firstName.equals( that.firstName )
                        && this.surname.equals( that.surname );
        } else {
            result = false;
        }

        return result;
    }
}
```

Controlling Inheritance

- In `Java` a subclass inherits all `public` methods and attributes.
- This is useful but public methods may lead to problems.
  - E.g. what if a malicious subclass overrides a method?
- It's clear that more control is needed.
- In `Java` you can restrict inheritance and method overriding:
  1. If you make a class `final` you can't extend it.
  2. If you make a method `final` you can't override it.

Making the Class Final

Java

```
public class Word {
    public void word( ) {
        System.out.println( "It is." );
    }
}
```

Making the Class Final

Java

```
public class Word {
    public void word( ) {
        System.out.println( "It is." );
    }
}

public class Rebuttal extends Word {
    // You can extend this class.
    public void word( ) {
        System.out.println( "Oh no it isn't." );
    }
}
```

Making the Class Final

Java

```
public class Word {
    public void word( ) {
        System.out.println( "It is." );
    }
}

public class Rebuttal extends Word {
    // You can extend this class.
    public void word( ) {
        System.out.println( "Oh no it isn't." );
    }
}

public final class LastWord extends Rebuttal {
    // You cannot extend this class.
    …
    @Override
    public void word( ) {
        System.out.println( "Oh yes it is." );
    }
}
```

Why Make a Class Final?

Why Make a Class Final?

Inheritance Violates Encapsulation

- With method overriding, client classes may change behaviour.
- Almost as bad as providing them direct attribute access.
- Here methods, not attributes, are exposed to modification.

Security: Makes sure the class does what it should do.

- An overridden method may misbehave.
  - Makes it impossible to enforce invariants.
- A `String` should behave as a `String`.
  - Should be impossible to override this method.

Maintenance: Clients may start to rely on overridden behaviour.

Making the Method Final

Java

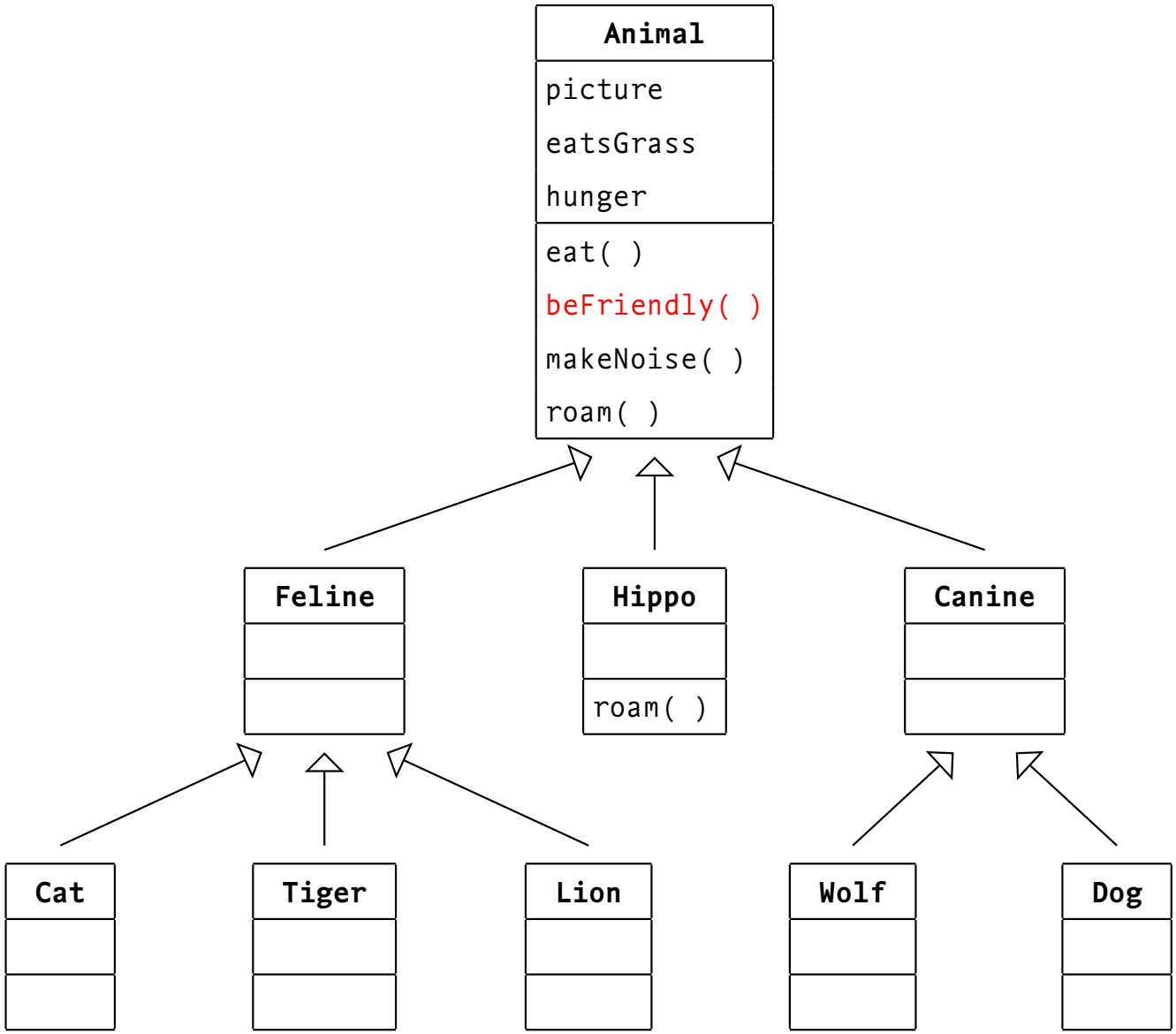
```
public class Example {
    // You may not override this method.
    public final void finalMethod( ) { … }
    // You may override this method.
    public void overridableMethod( ) { … }
}
```

Multiple Inheritance

- Let's introduce `Pets` to our `Animal` class hierarchy.
- The `Pets` can `beFriendly( )`.
- Other animals don't have `beFriendly( )` behaviour.
- Our design should allow for polymorphic pet variables.

Adding Pets to our Fota Application

Option I: Adding the `Pet` Method to the `Animal` Class



Adding Pets to our Fota Application

Option I: Adding the `Pet` Method to the `Animal` Class

Pros: The are two main advantages:

1. All `Pets` will inherit `Pet` behaviour, and
2. `Animal` can act as a polymorphic type for `Pets`.

Cons: There are also disadvantages:

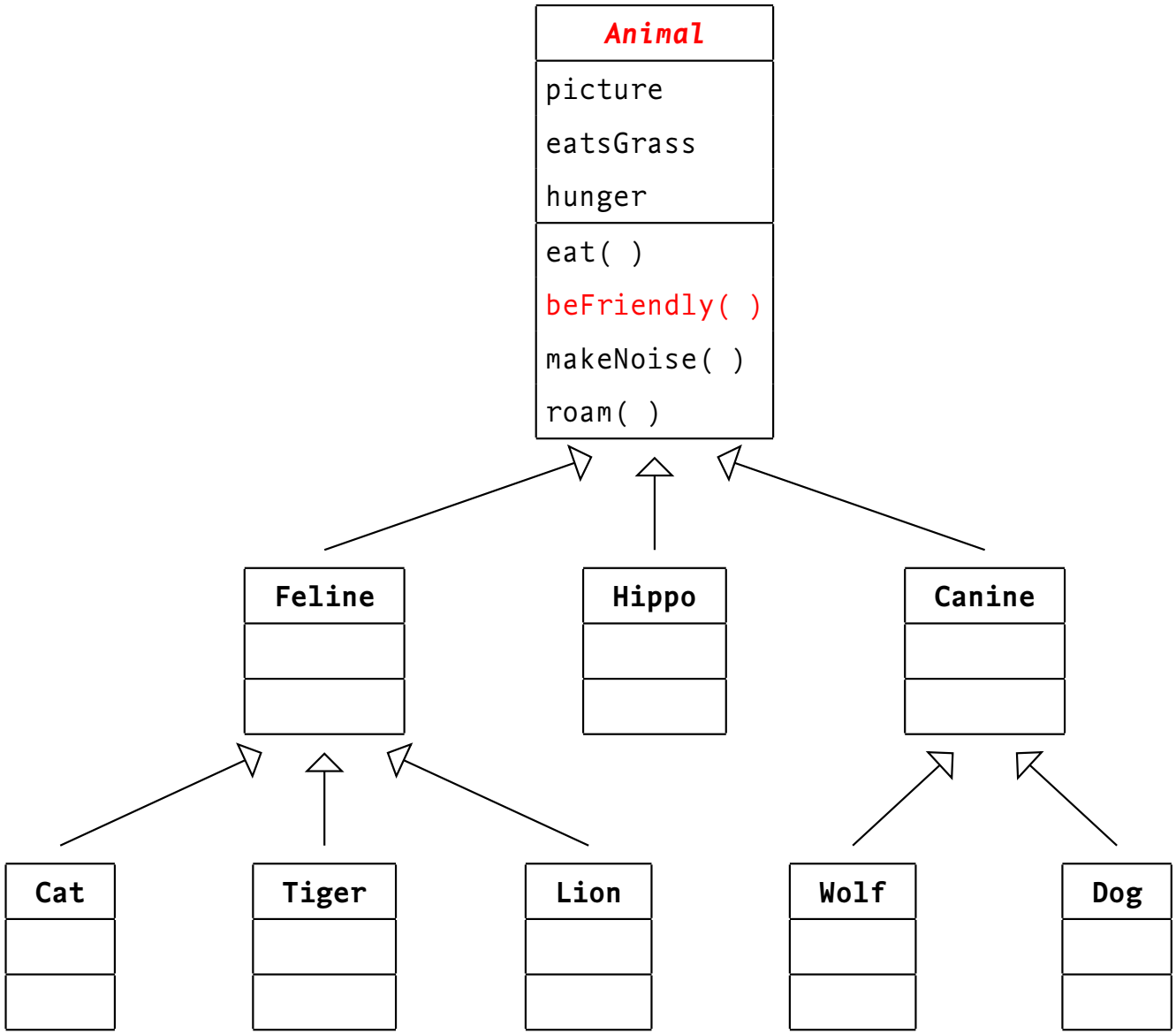
1. We don't have a proper `Pet` type.
2. Non-`Pets` will also get `beFriendly( )` behaviour.
3. Still must override `beFriendly( )` for `Dog` & `Cat`.

Conclusion: Clearly the disadvantages outweigh the advantages.

Cause: The Is-A test fails for non-`Pets`.

Adding Pets to our Fota Application

Option II: As Option I but Make `Animal` Class Abstract



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Adding Pets to our Fota Application

Option II: As Option I but Make `Animal` Class Abstract

Pros: The advantages are better than before.

1. We can make all animals behave appropriately.
2. `Animal` can act as a polymorphic type for `Pets`.

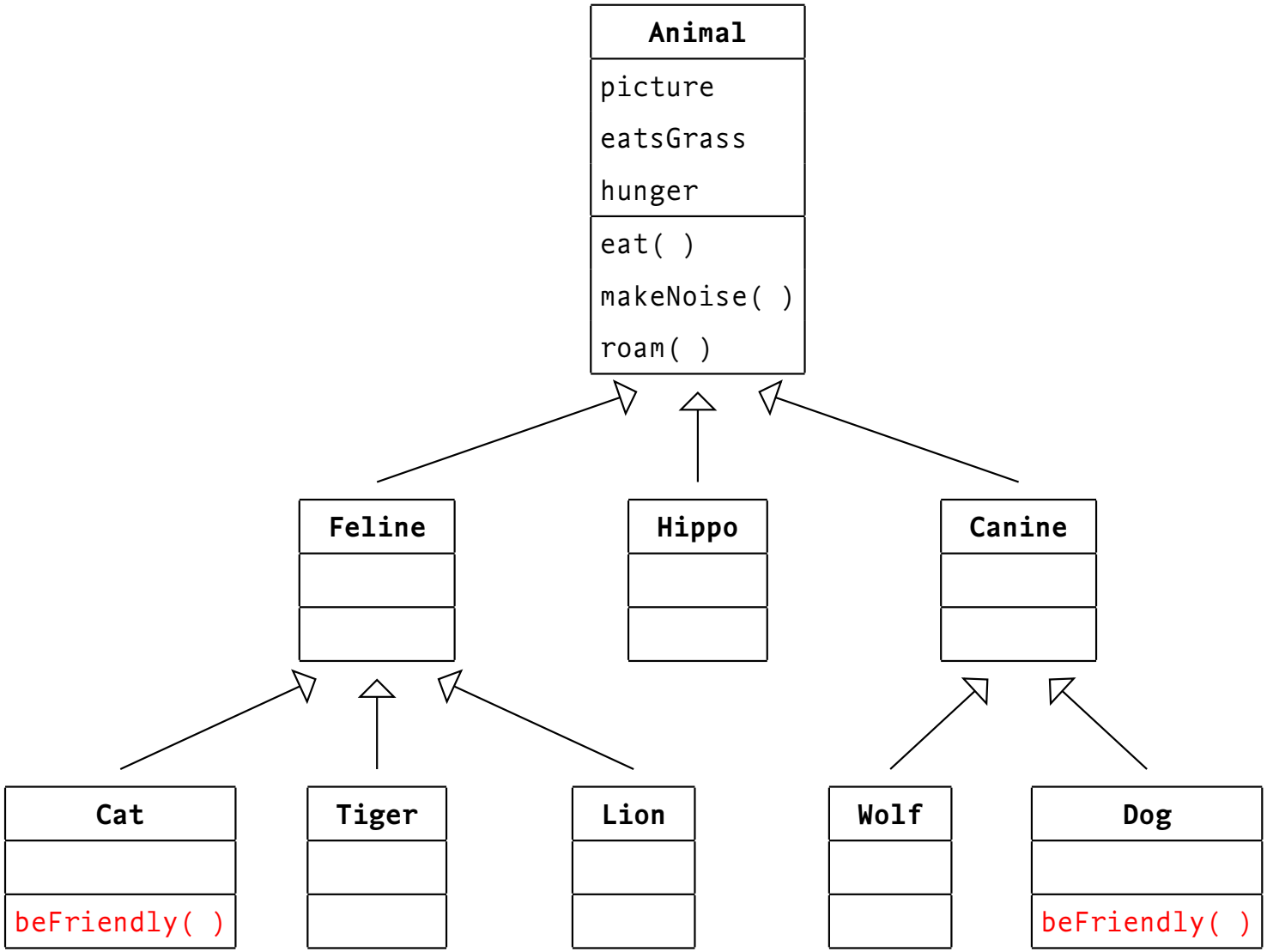
Cons: We still don't have a proper `Pet` type.
Must override `beFriendly( )` in all concrete classes.

Conclusion: This design is worse than Option I.

Cause: The Is-A test fails for non-`Pets`.

Adding Pets to our Fota Application

Option III: Put the `Pet` Method where It Belongs



Adding Pets to our Fota Application

Option III: Put the `Pet` Method where It Belongs

Pros: The following are some advantages.

- Definition of `beFriendly( )` is where it belongs.
- Implementing `beFriendly( )` requires little effort.
- All animals behave appropriately.

Cons: The following are some disadvantages.

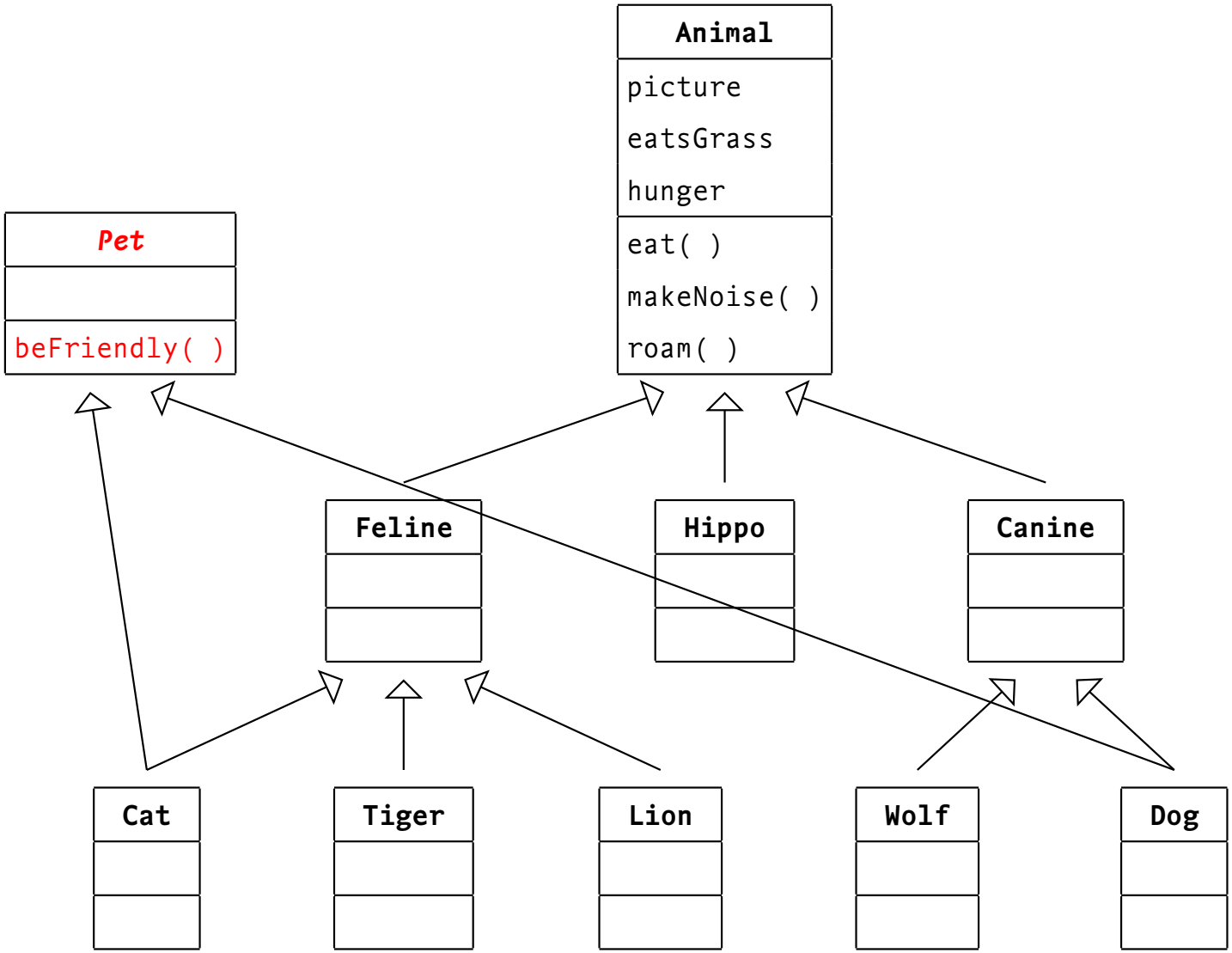
- We still don't have a proper `Pet` type.
- The `befriendly( )` method isn't abstract.
  - We can't guarantee a consistent `beFriendly( )`.
- We lose a proper polymorphic type for `Pets`.

Conclusion: This design makes `Pets` difficult to work with.

Cause: Polymorphism is a requirement for most applications.

Adding Pets to our Fota Application

Option IV: Two Superclasses for Pets



Adding Pets to our Fota Application

Option IV: Two Superclasses for `Pets`

Pros: The following are the advantages.

- The `beFriendly( )` method is where it belongs.
- Implementing `beFriendly( )` requires little effort.
- Guarantees consistent `beFriendly( )` definitions.
- `Pet` can act as a polymorphic type for pets.

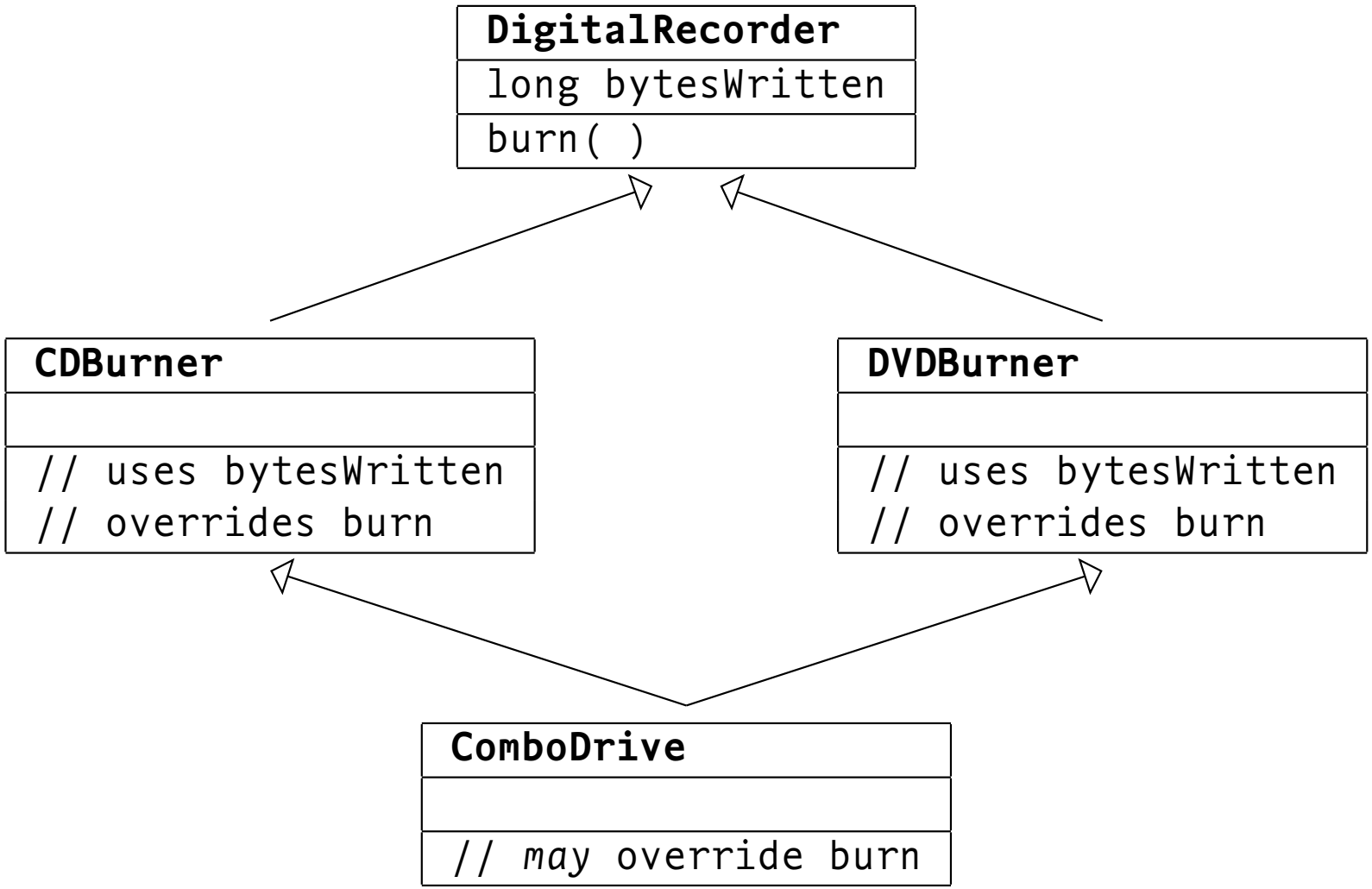
Cons: `Java` doesn't allow *multiple inheritance*.

Conclusion: This design is ideal but impossible.

Cause: A decision by the `Java` language designers.

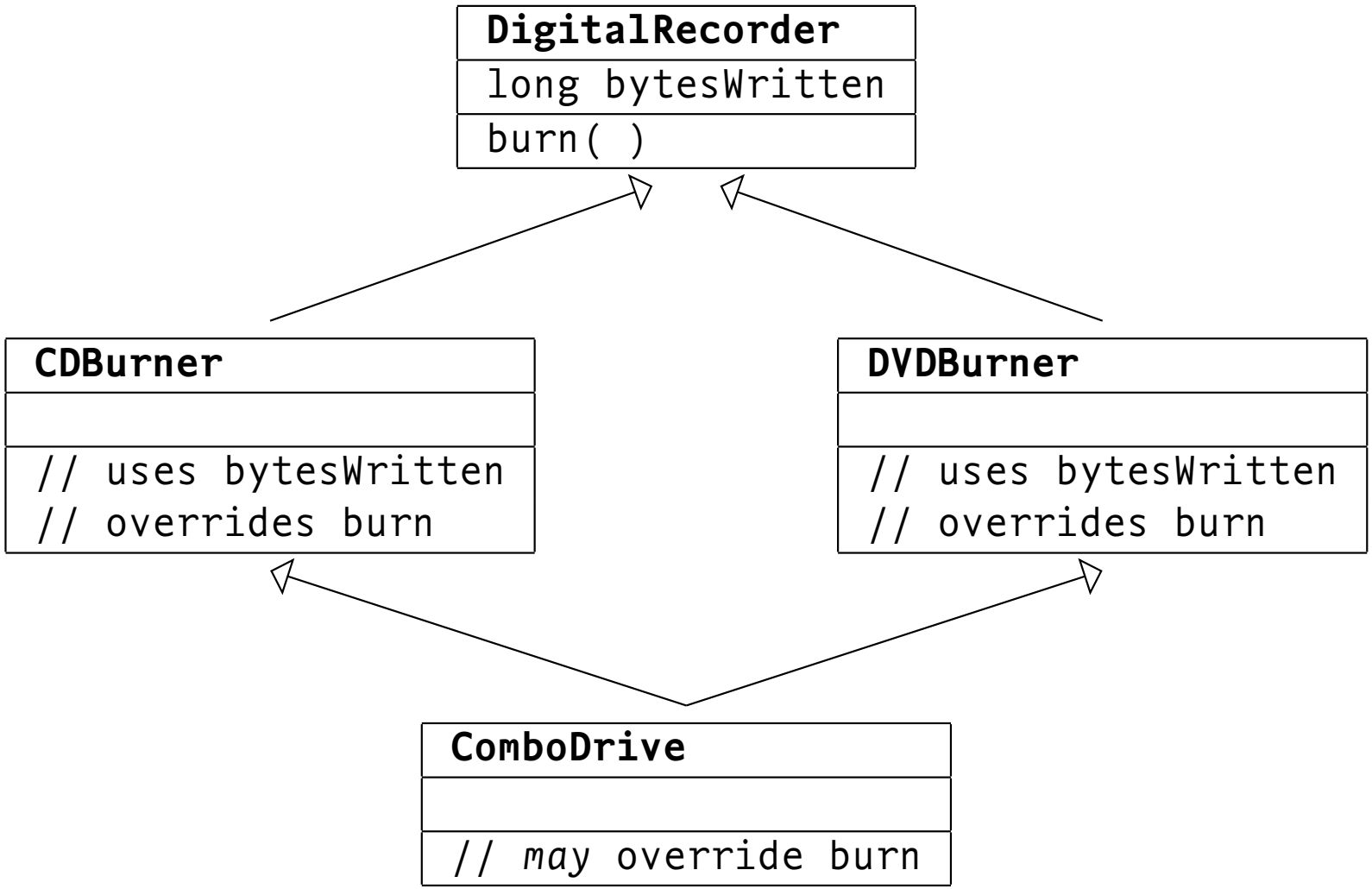
Deadly Diamond of Death

Different Assumptions about Valid Values for `bytesWritten`



Deadly Diamond of Death

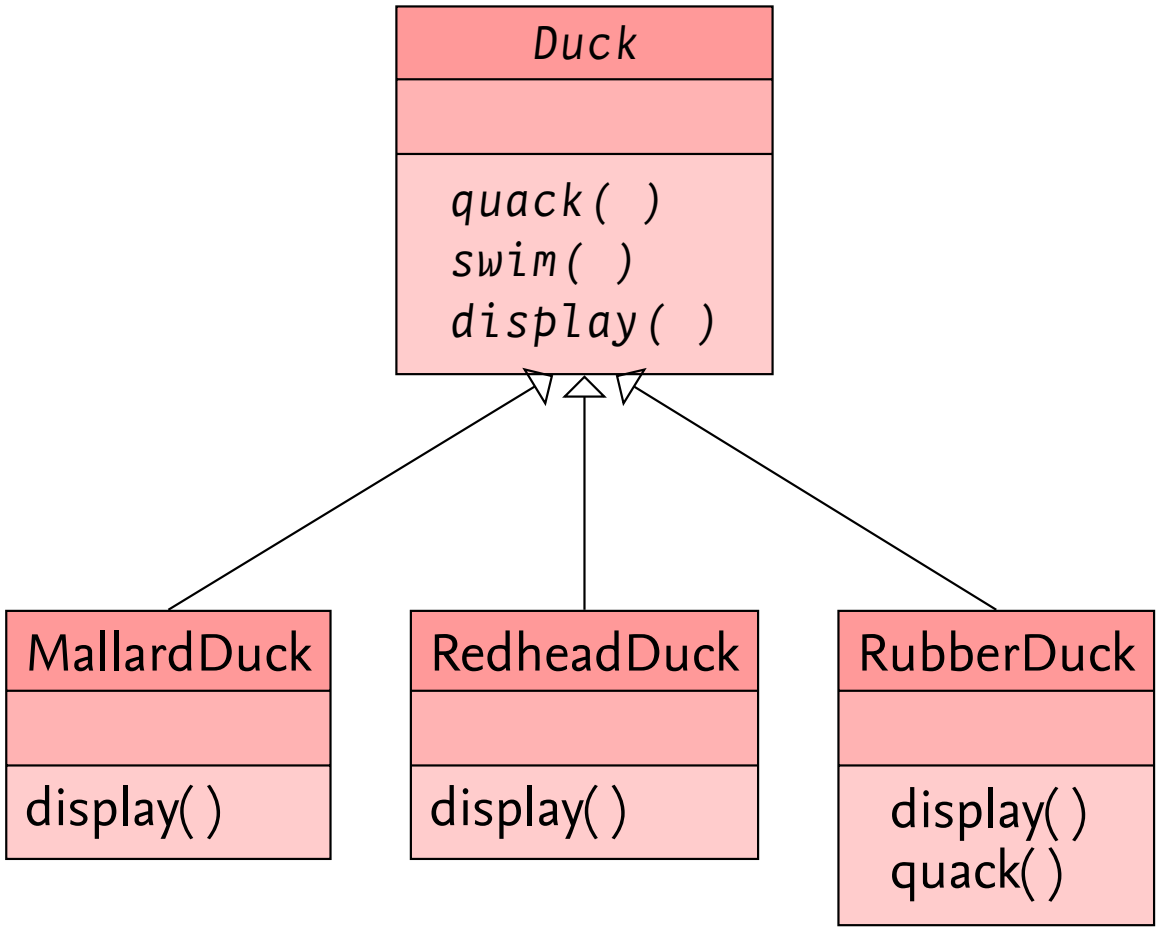
Which `burn( )` is Inherited by `ComboDrive`?



Implementing Duck Games

- Joe works at SimuDuck™.
- SimuDuck™ specialises in  pond simulation games.
  - These games involves lots of quacking and swimming  s.
- Joe is in charge of SimuDuck™'s most popular game.
- The game is written in Java and is based on inheritance.

The Design



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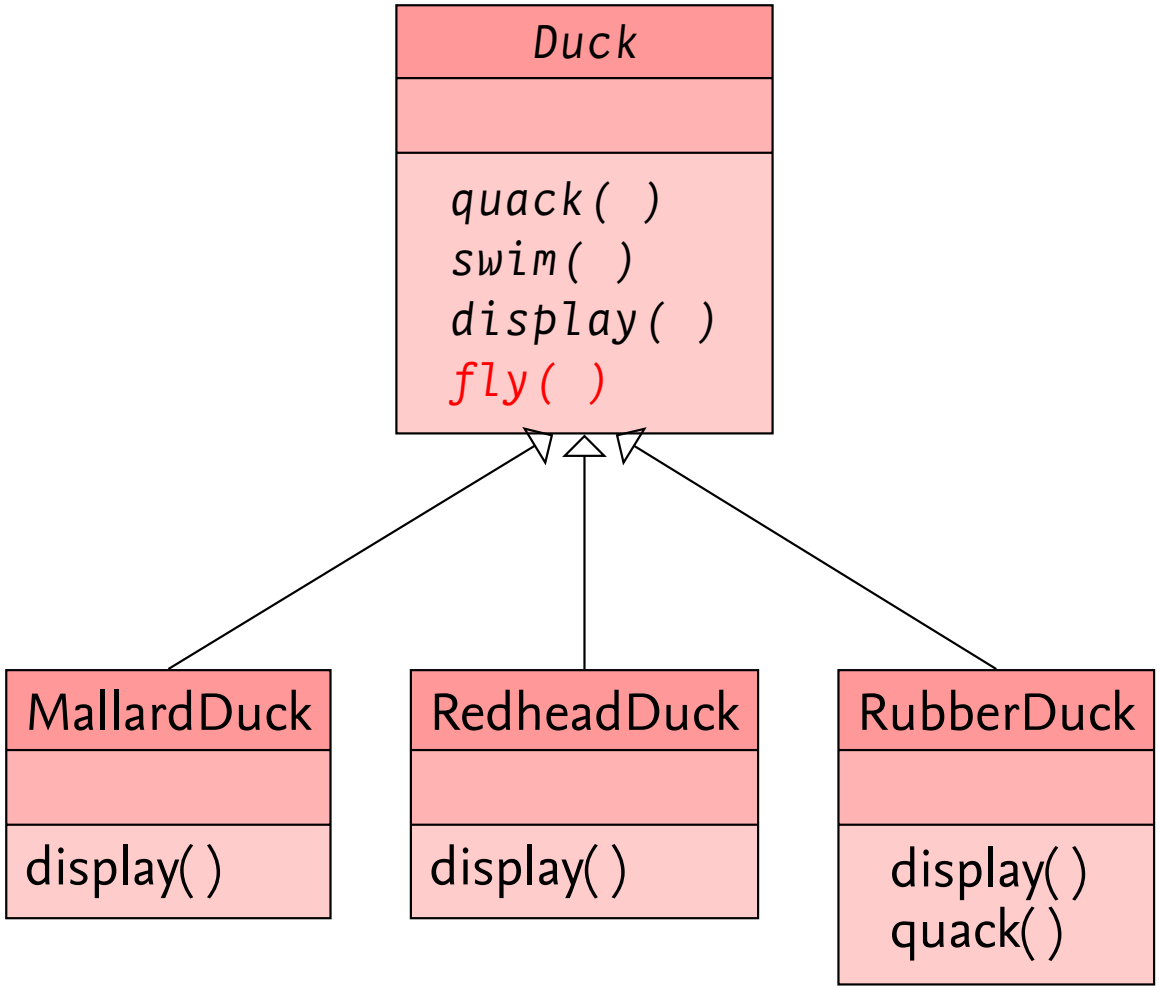
Enters Mr Change

The Design



The Verdict?

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What Has Gone Wrong?

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- At first Joe didn't understand what had gone wrong.
- It was inheritance that was causing the problem.
  - The `Duck` class defined the default `fly( )` behaviour.
  - This was inherited by *all* `Duck` subclasses.
  - None of the subclasses overrode the behaviour.
  - Therefore all  s had the default `fly( )` behaviour.
  - Including `RubberDucks`.

What Should Joe Do?

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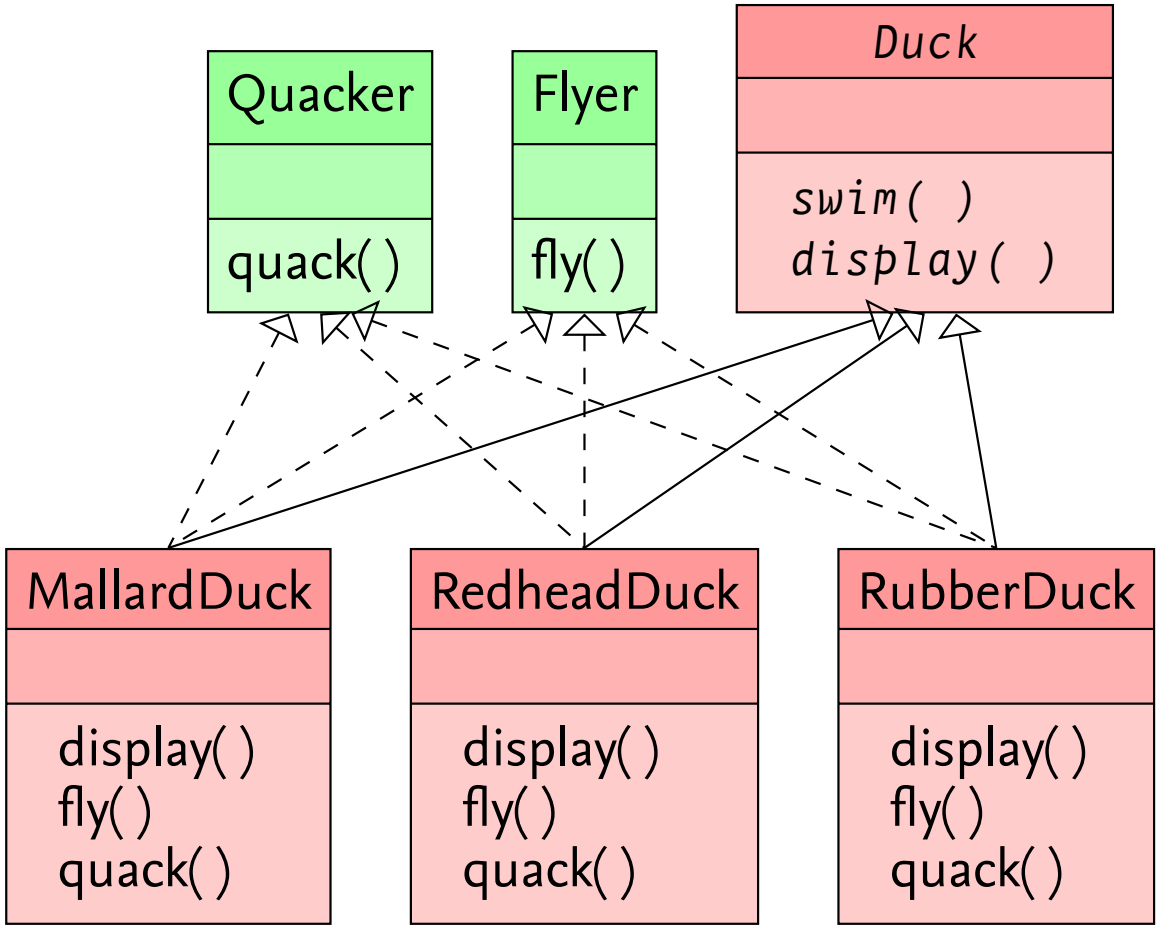
Should he override `fly( )` in the `RubberDuck` Class?

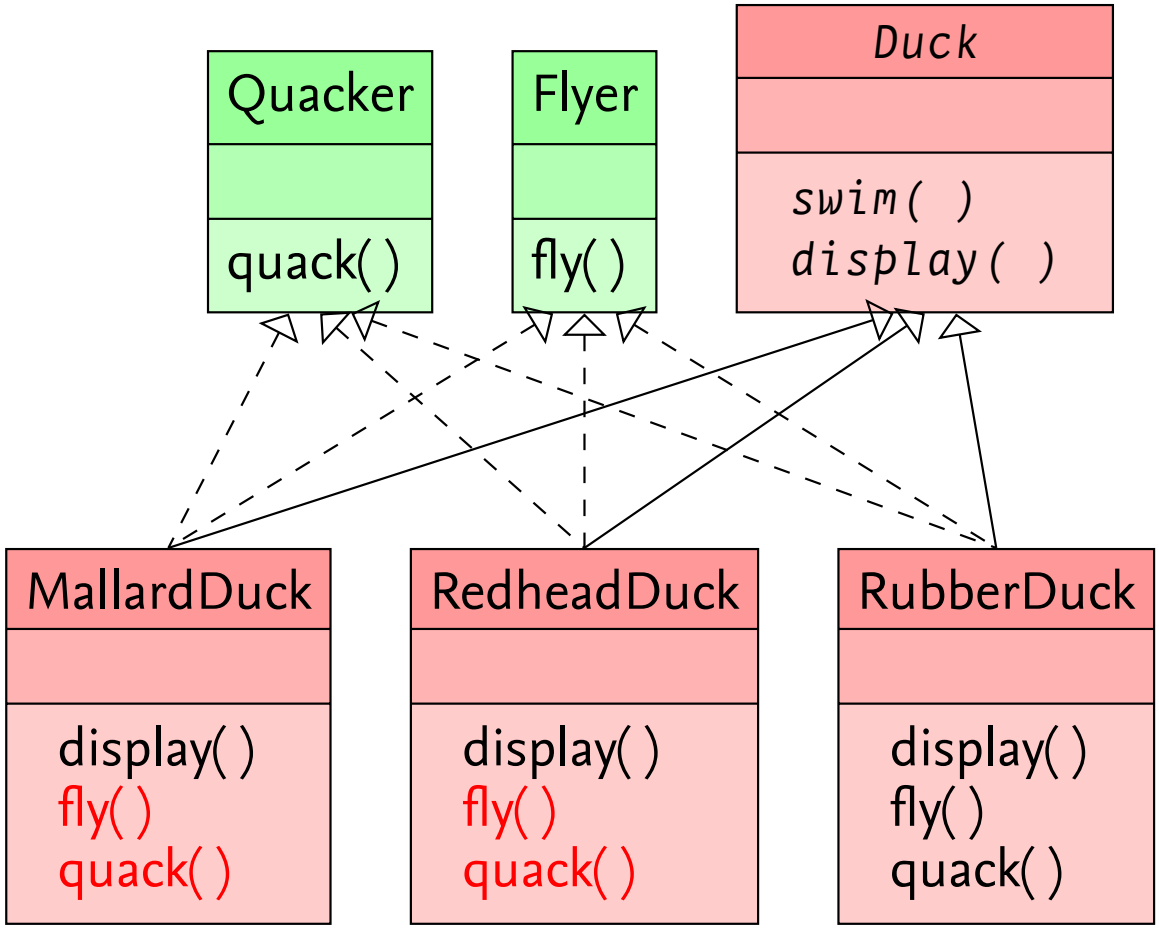
- If he did that he might have to duplicate code later.
  - For example, what if a `WoodenDecoyDuck` was added later?
  - `RubberDuck` and `WoodenDecoyDuck` were almost the same,
    - Yet shared no code....
- Of course he could introduce a common superclass.
  - But that would mean much work.
  - Also there was no guarantee that work would stop there.

Should he Use Interfaces?



Should he Use Interfaces?

Did Somebody say Code Duplication?



What Joe Really Wants

- Joe really wants software that doesn't change.
- He does realise that change is the only constant.
- Code changes should have little impact on existing code.
- That would save much time rewriting existing code.

First Design Principle

Encapsulate what Varies

- We've seen that inheritance didn't work for Joe.
  - When the (`Duck`) superclass changes this affects all subclasses.
- Interfaces cannot change but they have no implementation:
  - No code reuse.
- Encapsulate what Varies: Identify the aspects of your application that vary and separate them from what stays the same.
- We implement each aspect as a behaviour:
  - Implement separate classes for different behaviour.
  - Lets us choose specific behaviour by selecting a specific class.
  - Reusing the implementation comes for free.
  - Separates the implementation: increases flexability.

Encapsulate what Varies

- With interfaces, all classes *implemented* `Flyer` and `Quacker`.
- This is what caused the code duplication.
- We're going to encapsulate what varies:
  - We separate what varies: `fly( )` and `quack( )` behaviour.
  - We define a `Flyer` interface.
    - Encapsulate each different `fly( )` behaviour as separate class.
  - We also define a `Quacker` interface.
    - Encapsulate each different `quack( )` behaviour as separate class.
  - We reuse the behaviour in the actual `Duck` subclasses.
    - This is done using *delegation*.
    - (It involves a design pattern.)

Second Design Principle

- We need to design classes that implement  behaviour.
- Behaviour is *assigned* to specific `Duck` instance attributes.
  - Assiging behaviour can even be done at runtime.
- Program to an interface, not to an implementation.

Second Design Principle

Program to an Interface

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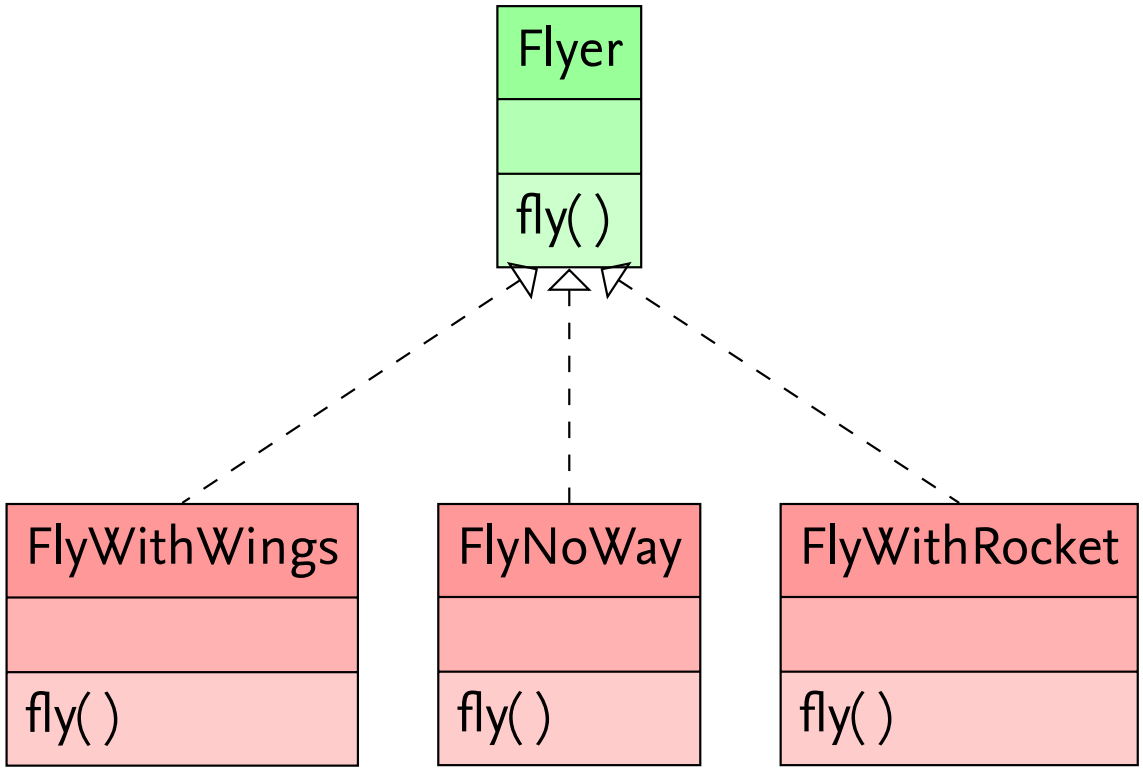
  - Assiging behaviour can even be done at runtime.
- Program to an interface, not to an implementation.

Programming to an Interface

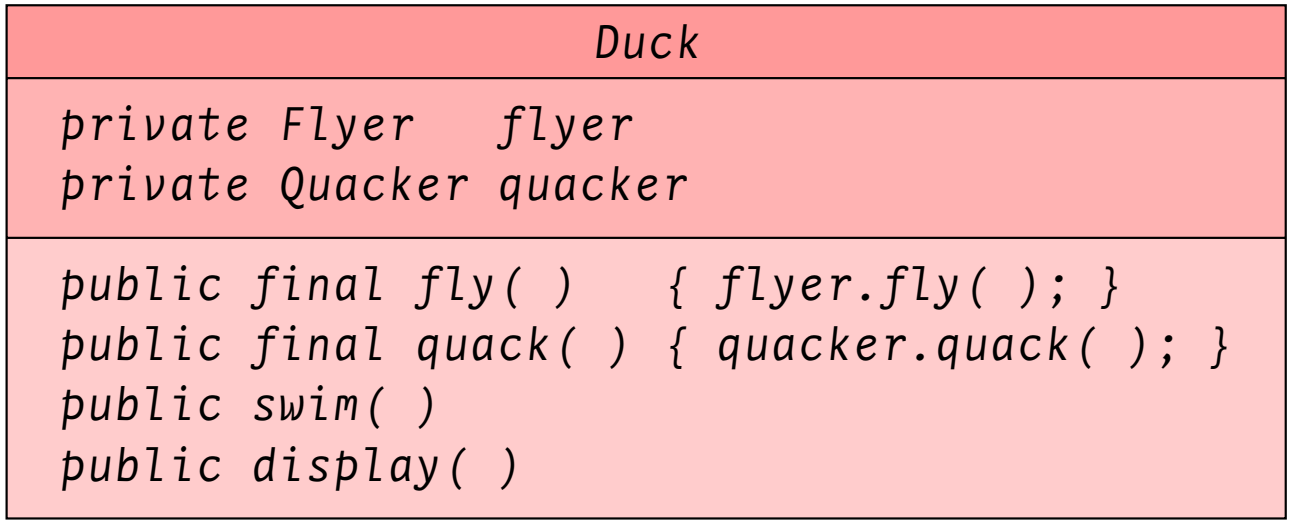
- We use an interface (a supertype) for each behaviour.
  - `Flyer`, `Quacker`, ...
  - Specific classes implement specific behaviours.
  - We use instances of these classes to use the behaviour.
- Before we depended on an *implementation:*
  - Default or overridden class behaviour.
- Now we depend on an interface:
  - An object with a type.
- Clients are now *unaware* of actual type and class of object.
  - This greatly reduces subsystem dependencies.

Implementing the `fly( )` Behaviour



Integrating the Duck Behaviour

Each Duck Delegates the fly( ) and quack( ) Behaviour



Implementing the MallardDuck

Java

```
public class MallardDuck extends Duck {
    public MallardDuck( ) {
        super( new SqueekQuack( ), new FlyWithWings( ) );
    }

    @Override
    public void display( ) {
        System.out.println( "MallardDuck here...." );
    }
}
```

Implementing the MutableDuck

Java

```
public class MutableDuck extends Duck {
    public MutableDuck( ) {
        super( new SqueekQuack( ), new FlyWithWings( ) );
    }

    public void setQuackBehaviour( Quacker quacker ) {
        // Assumes quacker is public/not final now.
        this.quacker = quacker;
    }

    public void setFlyBehaviour( Flyer flyer ) {
        // Assumes flyer is public/not final now.
        this.flyer = flyer;
    }

    @Override
    public void display( ) {
        System.out.println( "MutableDuck here...." );
    }
}
```

Inheritance versus Object Composition

Inheritance: Lets us create subclasses: *white-box reuse*.

- Subclass inherits superclass behaviour.
- Subclasses can override superclass behaviour.
- You get code reuse for free.
- You cannot change behaviour at runtime.
- Violates encapsulation.
  - Subclass may rely on superclass implementation.
  - Subclass may break when superclass is changed.

Composition: Lets you *compose* classes: *black-box reuse*.

- A client class may use an object.
- You get code reuse but it takes more effort.
- Lets you change behaviour at runtime.
- Respects encapsulation.
  - Helps encapsulated classes focus on a single task.

Has-A can be better than Is-A

- In our new design we rely on Has-A (more then on Is-A):
  - Each `Duck` has-a `flyer`, and
  - Each `Duck` has-a `quacker`.
- "Has-A" lets us implement behaviour by *composing* classes.
- The result is a more flexible design:
  - It lets us encapsulate behaviour.
  - We can change behaviour at runtime.

Third Design Principle

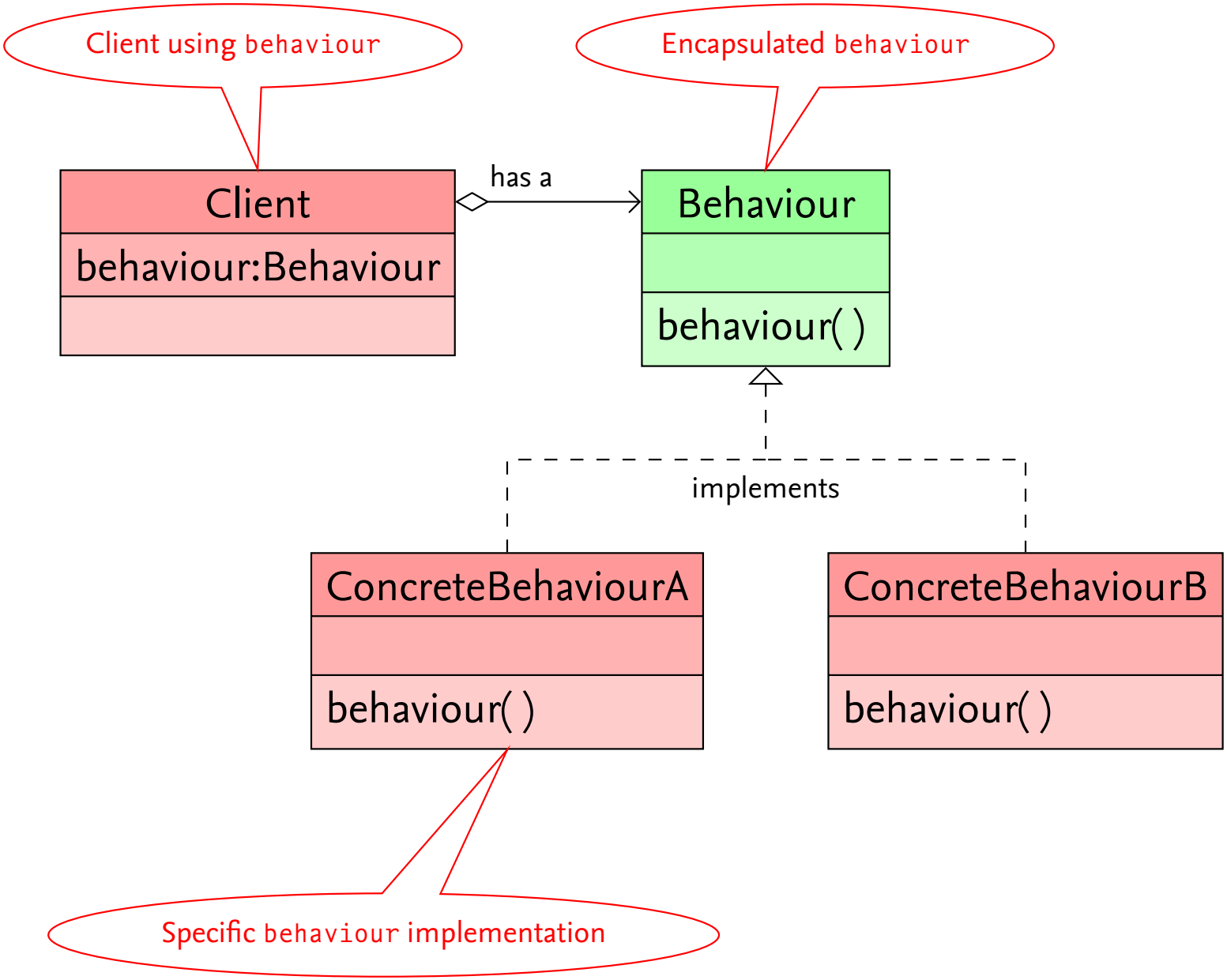
- In our new design we rely on Has-A (more then on Is-A):
  - Each `Duck` has-a `flyer`, and
  - Each `Duck` has-a `quacker`.
- "Has-A" lets us implement behaviour by *composing* classes.
- The result is a more flexible design:
  - It lets us encapsulate behaviour.
  - We can change behaviour at runtime.

Favour Composition over Inheritance.

The Strategy Pattern

- The *Strategy Pattern:*
  - Defines a class of algorithms;
  - Encapsulates each algorithm; and
  - Makes them interchangeable.
- Lets the algorithms vary independently from clients using it [Gamma et al. 2008].

Finally: Strategy Pattern



Question Time

Questions Anybody?

For Friday

- Study the presentation.
- Study Chapter 8 from the book.

Acknowledgements

- This lecture is partially based on
  - [Sierra, and Bates 2004].
  - [Freeman, and Freeman 2005].

Bibliography I


Freeman, Eric, and Elisabeth Freeman [2005]. *Head First Design Patterns*. O'Reilly. ISBN: 978-0-596-00920-5.


Gamma, Erich et al. [2008]. *Design Patterns Elements of Reusable Object-Oriented Software*. 36th Printing. Addison–Wesley. ISBN: 0-201-63361-2.


Sierra, Kathy, and Bert Bates [2004]. *Head First Java*. O'Reilly. ISBN: 978-0-596-00712-6.

About this Document

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- The LaTeX document class is `beamer`.