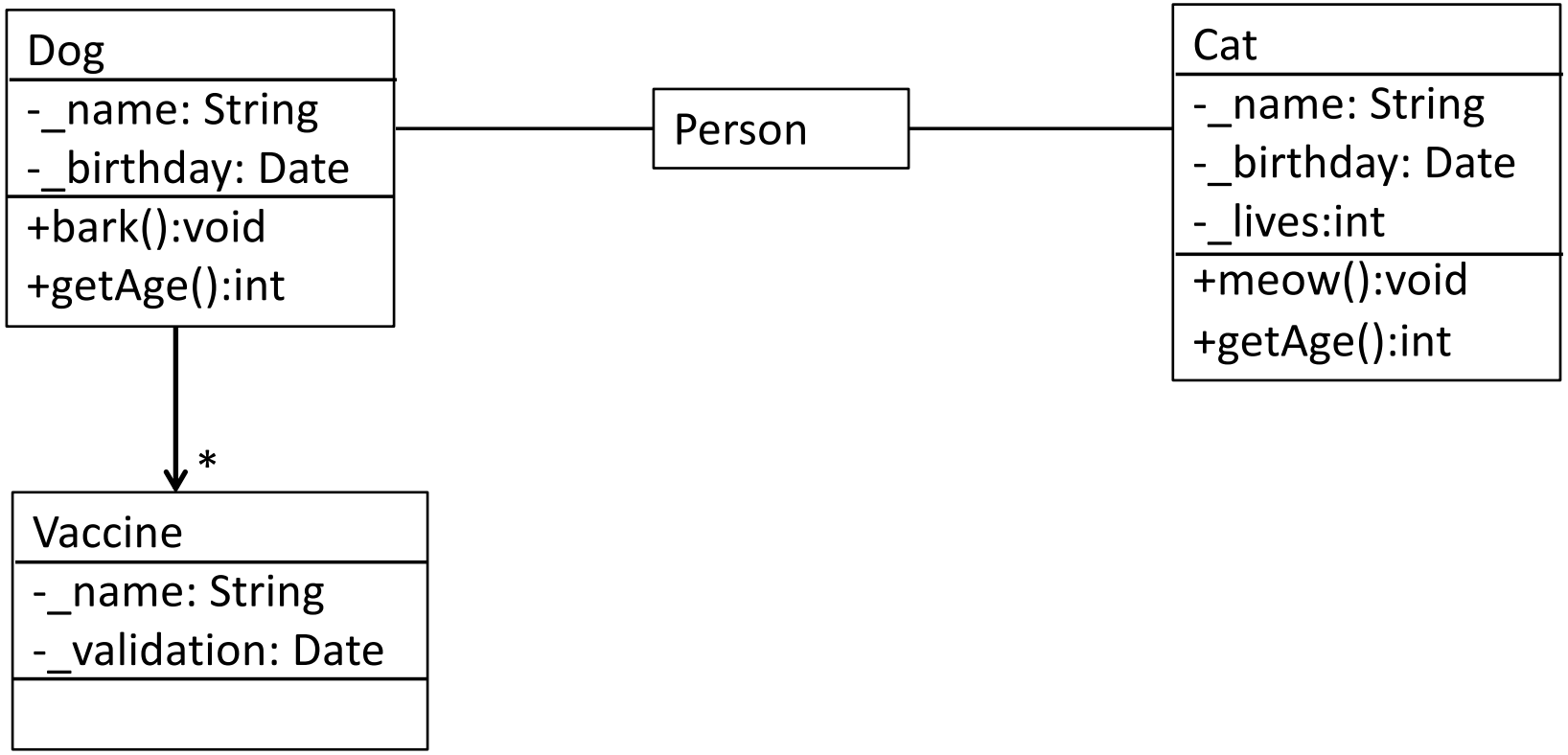
Inheritance

Code Reuse

Example: Shared Functionality - 1

A dog has a name, birthday, an owner and a set of vaccines



A cat has a name, birthday, an owner and a number of lives

Example: Shared Functionality - 2

```
public class Dog {
  private String _name;
  private Date _birthday;
  private Person _owner;
  private Vacine[] _vacine;

  public void bark() {
   System.out.println("ão ão");
  }

  public int getAge() {
    …
  }
}
```

```
public class Cat {
  private String _name;
  private Date _birthday;
  private Person _owner;
  private int _lifes;

  public void meow() {
    System.out.println("miau miau");
  }

  public int getAge() {
    …
  }
}
```

How to avoid code duplication?

Possible Solution: Use Composition

```
public class Animal {
  private String _name;
  private Date _birthday;
  private Person _owner;

  int getAge() {
    …
  }
}
```

```
public class Dog {

  private Animal _animal;
  private Vacine[] _vacine;

  public void bark() {
    …
  }
}
```

- Code duplication is avoided
- But there are problems with this solution:
  - The public interface of Dog and Cat is not the same as before
  - The relationship between **Cat** (**Dog**) and **Animal** is not a **has-a**
    - **Cat** is a **Animal**
    - **Dog** is a **Animal**

```
public class Cat {

  private Animal _animal;
  private int _numberLifes;

  public void meow() {
    …
  }
}
```

Relationships

- Object oriented programming leads to programs that are models
  - sometimes models of things in the real world
  - sometimes models of contrived or imaginary things
  - Two types of relationships between the modelled entities
    - **Has-a**
    - **Is-a**
- Chess
  - The Board **has** 32 chess pieces
  - A chess piece **has a** position
  - A chess piece **has a** color
  - A rook **is a** type of chess piece
  - A chess piece moves (changes position)
    - Behavior is specific for each type of chess piece

The **has-a** Relationship

- Objects are often made up of many parts or have sub data
  - chess piece: position, color, …
  - animal: owner, birthday, …
- The **has-a** relationship is modeled by composition
  - Each **has-a** relationship is implemented by one field internal to objects
  - Type of internal field depends on multiplicity of composition

The **is-a** Relationship

- Another type of relationship found in the real world
  - a rook is a chess piece
  - a queen is a chess piece
  - a student is a person
  - a teacher is a person
  - an undergraduate student is a student
- **is-a** usually denotes some form of specialization
- It is **not** the same as **has-a**

Is-a relationship - Inheritance

- The **is-a** relationship is modeled in object oriented languages via *inheritance*
- Classes can inherit from other classes
  - **Base** inheritance in a program on the real world things being modeled
  - Does “an A is a B” make sense? Is it logical?
- In Java the `extends` keyword is used in the class header to specify which preexisting class a new class is inheriting from

```
public class Dog extends Animal
```

- Animal is said to be
  - the parent class of Dog
  - the super class of Dog
  - the base class of Dog
  - an ancestor of Dog
- Dog is said to be
  - a child class of Animal
  - a subclass of Animal
  - a derived class of Animal
  - a descendant of Animal

Results of Inheritance

public class B extends A

- The subclass inherits (gains) all fields and instance methods of the super class, **automatically**
  - The non-static fields defined in A are also part of the state of every B object
- Additional methods can be added to subclass
  - Called specialization
- The subclass can replace (redefine, **override**) methods from the super class
- Inheriting all member does not mean direct access
  - private and package-private members not accessible

Example

Animal

- **Has**:
  - birthday, name and owner
- **Do**:
  - getAge(), getOwner()

- **Dog**
  - **Is-a** Animal
  - **Has**:
    - birthday, name, owner
    - vacines
  - **Do**:
    - getAge(), getOwner(),
    - bark(), waggingTail()

```
class Animal {
  private String _name;
  private Date _birthday;
  private Person _owner;

  public int getAge() {
    … }

  public Person getOwner() {
    …}
}
```

```
class Dog extends Animal {
  private Vacine[] _vacine;

  public void bark() {
    … }

  public void waggingTail()
  { … }
}
```

```
class Cat extends Animal {
  private int _lifes;

  public void meow() {
    …
  }
  public void climb() {
    …
  }
}
```

Overriding Methods

- A subclass can override (redefine) the methods of the superclass
  - Objects of the subclass type will use the new method
  - Objects of the superclass type will use the original
- This allows to make more methods that are common to several subtypes using the right abstraction
- Cat and Dog have a similar method (same semantic) but with a different implementation
  - bark() and meow(): *animal talk or make noise*
  - But should not have both methods at Animal
  - Solution: have a method makeNoise() at Animal
  - And must be implemented in both classes (Cat and Dog)
    - Otherwise, the computation would be the same

Solution with Overriding

```
public class Animal {
  private String _name;
  private Date _birthday;
  private Person _owner;

  public int getAge() {
    …
  }

  public Person getOwner() {
    …
  }
  public void makeNoise() {
  }
}
```

```
public class Dog extends Animal {
  private Vacine[] _vacine;

  public void waggingTail() {
    …
  }
  public void makeNoise() {
   System.out.println("ão ão");
  }
}
```

```
public class Cat extends Animal {
  private int _lifes;

  public void climbTree() {
    …
  }
  public void makeNoise() {
    System.out.println("miau miau");
  }
}
```

Inheritance in Java

- Java is a pure object oriented language
- All code is part of some class
- All classes, except one, **must** inherit from exactly one other class
- The `Object` class is the *cosmic super class*
  - The `Object` class does not inherit from any other class
  - The `Object` class has several important methods: `toString`, `equals`, `hashCode`, `clone`, `getClass`
- Implications:
  - All classes are descendants of `Object`
  - Al classes and thus all objects have a `toString`, `equals`, `hashCode`, `clone`, and `getClass` method
    - `toString`, `equals`, `hashCode`, `clone` normally overridden

Inheritance in Java

- If a class header does not include the extends clause the class extends the `Object` class by default

  ```
  public class Animal
  ```

  - `Object` is an ancestor to all classes
  - it is the only class that does not extend some other class
- A class extends exactly one other class
- Extending two or more classes at the same time is designated as *multiple inheritance.*
  - Java does not support this directly, rather it uses *Interfaces*.
  - C++ supports

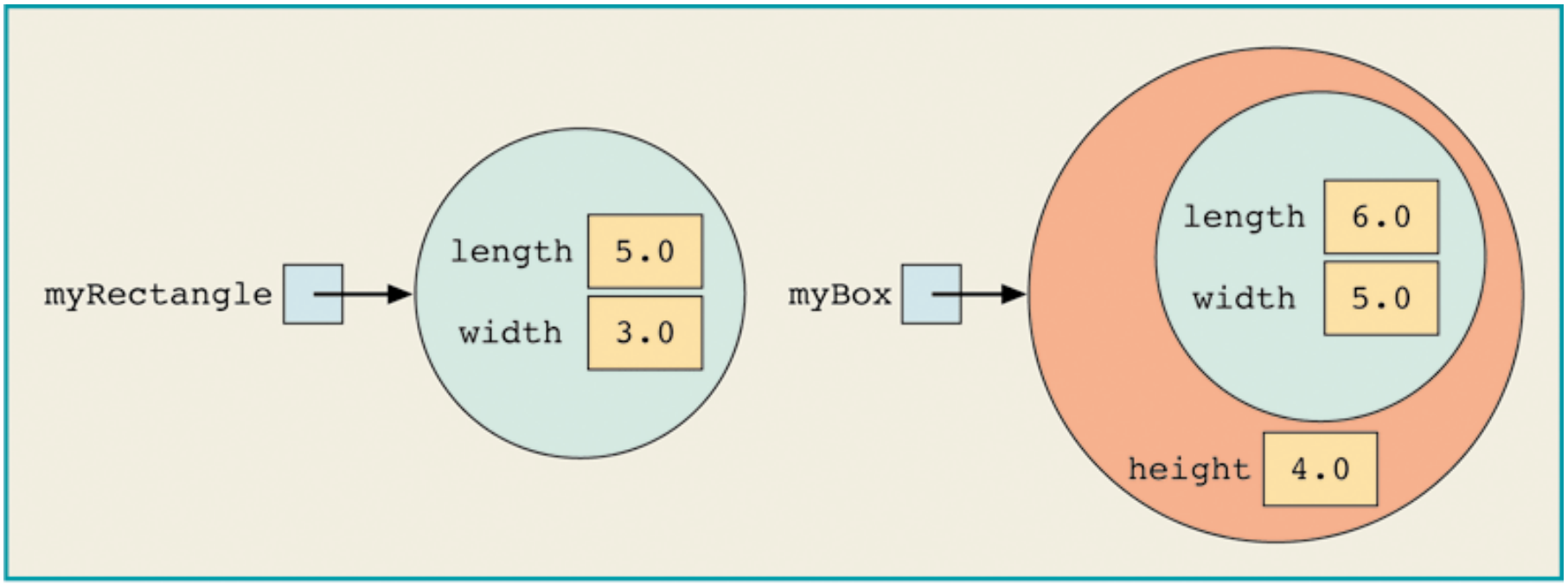
Objects `myRectangle` and `myBox`

```
public class Rectangle {
  private int _length;
  private int _width
  …
}
```

```
public class Box extends Rectangle {
  private int _height;

  …
}
```

```
Rectangle myRectangle = new Rectangle(5, 3);
Box myBox = new Box(6, 5, 4);
```



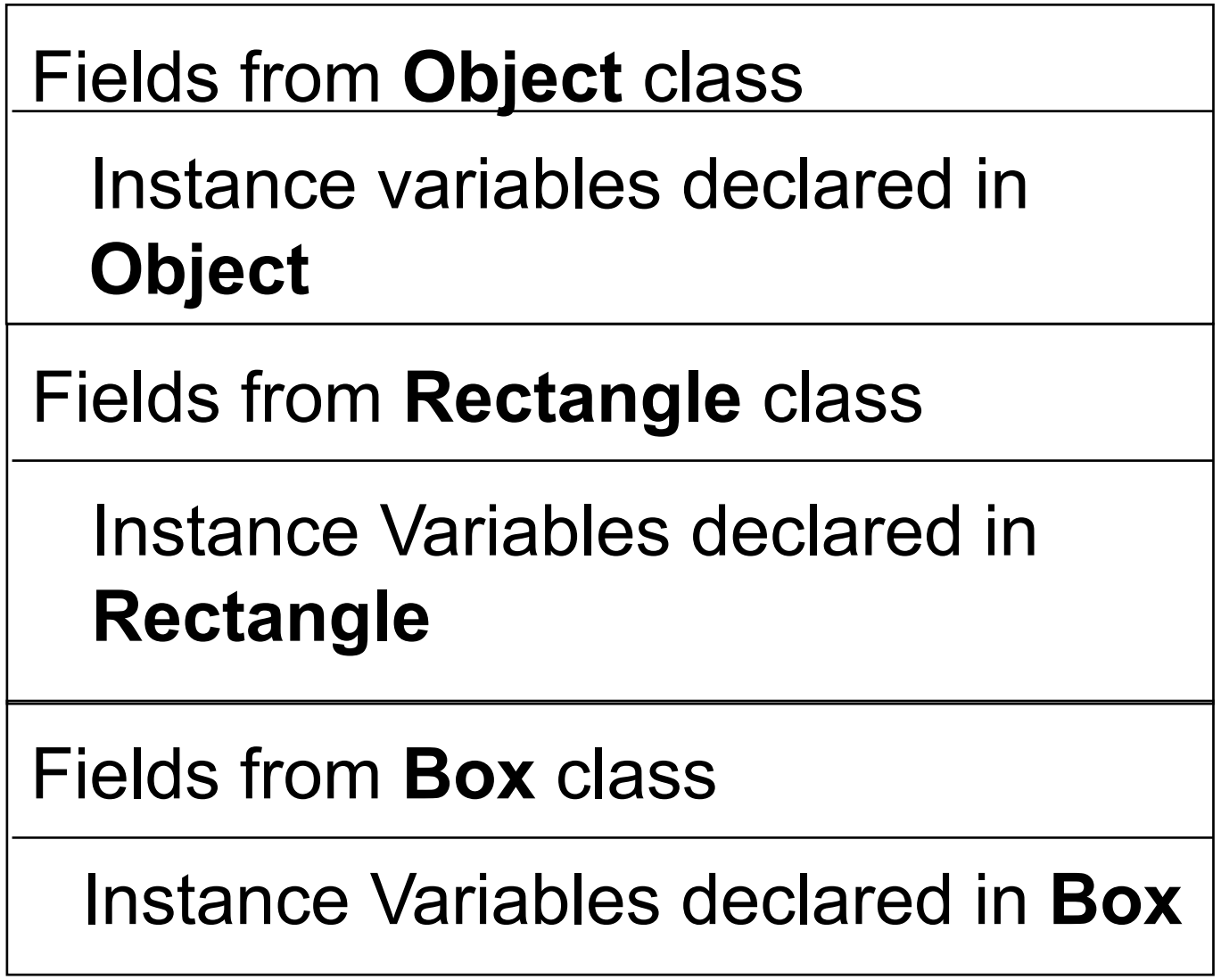
The Real Picture with Inheritance

A **Box** object

state

behavior

Available methods are all methods from **Object**, **Rectangle** and **Box**

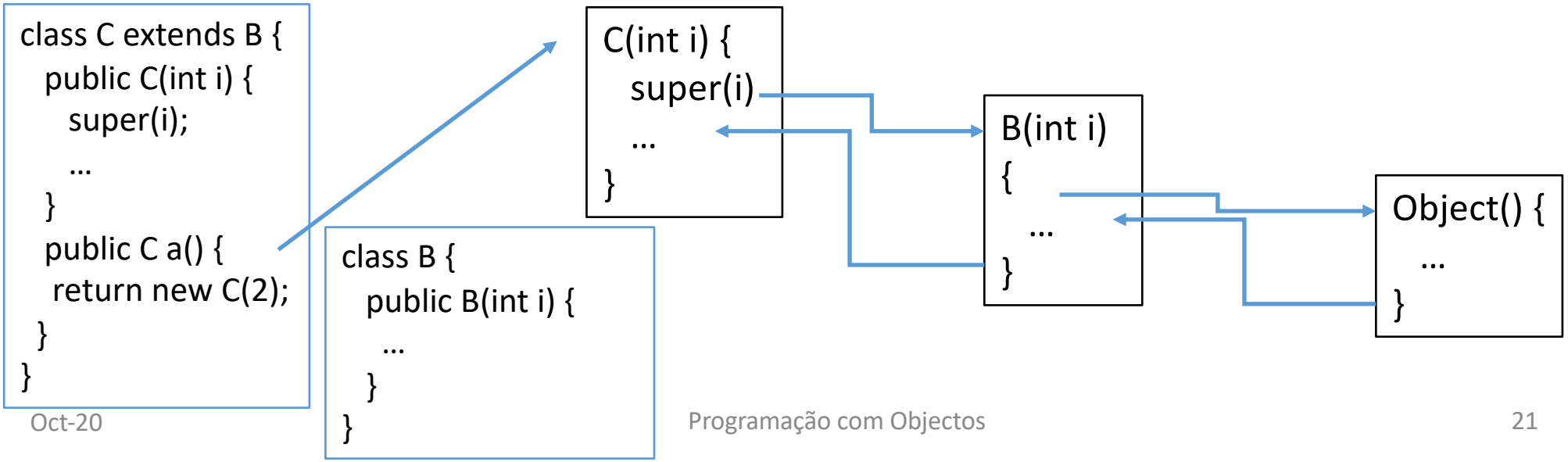


Constructors with Inheritance

- Constructors handle initialization of objects
- When creating an object with one or more ancestors (every type except Object) a chain of constructor calls takes place
- The reserved word `super` may be used in a constructor to call one of the parent's constructors
  - must be first line of constructor
- If no parent constructor is explicitly called the default **no-arg** constructor of the parent is called
  - if no default constructor exists a syntax error results
- Cannot invoke parent constructor and another constructor in the same class
  - no `super();this();` allowed
  - One or the other, not both

Constructors in Subclasses

- Constructors are *not* inherited!
- Chain of constructor calls
  - subclass constructor invokes superclass constructor
    - Implicitly or explicitly
    - To call explicitly, use super(*params*)
    - Superclass constructor call must be first statement in subclass constructor
  - `Object` constructor is always fired last
    - But it is the first to be executed



Invoking methods of the superclass

- How to invoke an accessible method of the superclass in the context of the subclass?

- Method not overridden in subclass
  - Just invoke the method
  - `MethodName(parameter list)`

- Method Overridden in subclass
  - If invoke `MethodName(parameter list)` the invoked method is the one defined in subclass
  - Must use the **super** keyword to specify that we want to invoke the version defined for the superclass

    `super.MethodName(parameter list)`

Override and Overloading

```
public class Rectangle{
  private int _length, _width;

  public Rectangle(int l, int w) {
    _length = l;
    _width = w;
  }
  public int area() {
   return _length * _width;
  }
  public void print() {
    System.out.println("length : " + _length);
    System.out.println("width : " + _width);
  }
  public void setDimension(double l, double w) {
    _length = (l >= 0) ? l : 0;
    _width = (w >= 0) ? w : 0;
  }
}
```

Override and Overloading

```
public class Rectangle{
  public void area()
  public void print()
  public void setDimension(double l, double w)
}
```

```
public class Box extends Rectangle {
 private int _height;
 public Box(int l, int w, int h) {
  super(l, w);
  _height = h;
 }
 public void volume() {
  return area() * _height;
 }
 public void print() {
  super.print();
  System.out.println("height: " + _height);
 }
 public void setDimension(double l, double w, double h) {
  super.setDimension(l, w);
  if (h >= 0) _height = h;
  else _height = 0;
 }
}
```

Inherited methods?

- *area* *setDimension(l,w)*

Overridden methods?

- *print*, ~~*setDimension(l,w)*~~

Box **overloads** *setDimension*

- Same name but different parameters

New methods (specialization)

- volume
- setDimension(l,w,h)

The Keyword `super`

- `super` is used to access something (any protected or public field or method) from the super class that has been overridden
- Box's `print` makes use of the `print` in Rectangle by calling `super.print()`
- Without the super calling `print()` would result in infinite recursive calls
- Java does not allow nested supers

```
super.super.print()
```

Overloading vs. Overriding

- Don't confuse the concepts of overloading and overriding
- Overloading deals with multiple methods with the same name in the same class, but with different signatures
- Overriding deals with two methods, one in a parent class and one in a child class, that have the same signature
- Overloading lets you define a similar operation in different ways for different parameter types
- Overriding lets you define a similar operation in different ways for different object types

Hiding Fields

- The concept of *overriding* can also be applied to fields and is called *shadowing variables* or *hiding fields*
- Define a field in subclass with the same name as a field in the superclass
  - Type can be different
  - Code in subclass accesses the field defined in subclass
  - Code in superclass accesses the field defined in superclass
  - To access superclass field in subclass use *super* keyword
    - super.fieldName
- Hiding fields makes code difficult to read

Access Modifiers and Inheritance

- **public**
  - accessible to all classes
- **private**
  - accessible only within that class. Hidden from all sub classes.
- **protected**
  - accessible by classes within the same *package* and all descendant classes
- Fields ***should*** be private
- **protected** methods are used to allow descendant classes to modify instance variables in ways other classes can't

Comments on Private vs. Protected

- Use *private* so that
  - Superclass implementation can change without affecting subclass implementations
- Use *protected* when
  - Superclass should provide a service only to its subclasses
  - Should not provide service to other clients
- Avoid *protected* fields
  - Do not preserve the *encapsulation* principle
  - Provide set and get methods to access *private* fields

Using protected Fields

- Advantages
  - Subclasses can modify values directly
  - Slight increase in performance
    - Avoid set/get method call overhead (may not be true)
- Disadvantages
  - No validity checking
    - subclass can assign illegal value
  - Implementation dependent
    - subclass methods more likely dependent on superclass implementation
    - superclass implementation changes may result in subclass modifications
      - Fragile (brittle) software

final Method

- Can declare a method of a class *final* using the keyword `final`

```
public class A {
   public final void doSomeThing() {
      //...
    }
}
```

- **final** method of **cannot** be overridden derived classes

```
public class B extends A {
    public void doSomeThing() {
       //...
    }
}
```

- Compilation error

final Class

- Can also declare a `class` final using the keyword `final`
- If a `class` is declared `final`, then no other class can be derived from this class

Invoking methods in Constructors

- What is the problem with

```
public class A {
  public A() {
    doSomeThing();
  }

  public void doSomeThing() {
    //...
  }
}
```

```
public class B extends A {
  private String _myStr;

  public B(String str) {
    _myStr = str;
  }

  public void doSomeThing() {
    System.out.println(_myStr);
  }
}
```

- None
  - Unless we consider inheritance
  - Invoked method can be overridden in subclasses
  - May access to fields that are not initialized yet
- Safe methods (cannot be overridden)
  - final
  - private

Any Problem?

```
public class Animal {
  private String _name;
  private Person _owner;

  public Animal(String n, Person p) {
    _name = n;
    _owner = o;
  }

  public void makeNoise() {
  }
  // …
}
```

```
public class Dog extends Animal {
  private Vacine[] _vacine;

  public Dog(String n, Person p, Vacine[] v) {
    super(n, p);
    _vaccine = v;
  }

  public void makeNoise() {
    System.out.println("ão ão");
  }
}
```

```
public class Cat extends Animal {
  private int _numberLifes;

  public Cat(String n, Person p) {
    super(n, p);
    _numberLifes = 7;
  }

  public void makeNoise() {
    System.out.println("miau miau");
  }
}
```

Yes!

- Does it make sense to have the following?
  - Animal a = new Animal("42", aPerson);
  - **No!**
- More problems?

```
Public class Cow extends Animal {
  private String _color;

  public Cow(String n, Person p, Color c) {
     super(n, p);
    _color = c;
  }
}
```

  - makeNoise() is not overridden and it should be!

Abstract Classes

- Sometimes, when refactoring code, superclasses do not correspond to real entities
  - Are an abstraction
    - Example: *Dog* and *Animal*
  - Represented as an abstract class in Java
- Abstrac class in Java
  - public **abstract** class A { …. }
  - Cannot be instantiated (but can define constructors)
    - Unlike *normal* classes – concrete classes
  - Can have methods without any implementation
    - Called ***abstract*** methods
    - A method that has only the heading with no body
    - And use *abstract* keyword
    - public abstract void doSomething();

Abstract Classes - 2

- An abstract class can contain fields, constructors, finalizers, concrete and abstract methods
- Static, private, final methods cannot be abstract
- When you extend an *abstract* class with *abstract* methods:
  - Subclass does not override all abstract methods
    - Subclass must be declared abstract
  - Subclass overrides all abstract methods
    - Subclass can be a concrete class
      - Can instantiate subclass (unless it is declared abstract)
    - Or it can be declared as abstract

Correct Animal Implementation

```
public abstract class Animal {
  private String _name;
  private Person _owner;

  public Animal(String n, Person p) {
    _name = n;
    _owner = o;
  }

  public abstract void makeNoise();
// …
}
```

```
public class Cow extends Animal {
  private String _color;

  public Cow(String n, Person p,
             Color c) {
    super(n, p);
    _color = c;
  }
}
```

Compile this code.
What happens?

Compilation error in Cow. Why?

- Inherits an abstract method
- Does not implement it

- Solutions

1. Implement method in Cow
2. Declare Cow as abstract

Type Compatibility

- Java is a *strongly typed* language.
- Compatibility
  - when you assign the value of an expression to a variable, the type of the expression must be compatible with the declared type of the variable: it must be the same type as, or a subtype of, the declared type
  - `null` object reference is compatible with all reference types.

Type conversion - 1

- The types higher up the type hierarchy are said to be *wider*, or *less specific* than the types lower down the hierarchy. Similarly, lower types are said to be *narrower*, or *more specific*.
- *Widening conversion*: assign a subtype to a supertype
  - Upcasting - It is safe
  - Can be checked at compile time. No action needed
- *Narrowing conversion:* convert a reference of a supertype into a reference of a subtype
  - Downcasting – Not safe
  - *M*ust be explicitly converted by using the *cast* operator
    - **(Type)**

```
Rectangle r = new Box();
Box b = (Box)r;
```

Type conversion - 2

- Explicit type casting: a type name within parentheses, before an expression
  - For upcasting: **not** necessary
  - For downcasting: **must** be provided

e.g.

```
String str = "test";
Object obj1 = (Object)str;
Object obj2 = str;
String str1 = obj1;
String str2 = (String)obj1;
Double num = (Double)obj1;
```

- If the compiler can tell that a narrowing cast is incorrect, then a compile time error will occur
- If the compiler cannot tell, then the run time system will check it. If the cast is incorrect, then a *ClassCastException* will be thrown

E.g. Student is subclass of Person

```
public class TypeTest {
   static Person[] p = new Person[10];

   static
   {
            for (int i = 0; i < 10; i++) {
              if(i<5)
                 p[i] = new Student();
              else
                 p[i] = new Person();
            }
   }

   public static void main (String args[]) {
            Person o1 = (Person)p[0];
            Person o2 = p[0];
            Student o3 = p[0];
            Student o4 = (Student)p[0];
            Student o5 = p[9];
            Student o6 = (Student)p[9];
            int x = p[0].getStudentNumber();
   }
}
```

```
%> javac TypeTest.java
TypeTest.java:17 incompatible types
found    : Person
required : Student
            Student o3 = p[0];
                         ^

TypeTest.java:19 incompatible types
found    : Person
required : Student
            Student o5 = p[9];
                         ^

TypeTest.java:21: cannot resolve  symbol
symbol   : method getStudentNumber ()
location:  class Person
          int x = p[0].getStudentNumber();
                      ^
3 errors
```

After commenting out these three ill lines:

```
%> java typeTest
Exception in thread "main"
      java.lang.ClassCastException: Person
            at typeTest.main(typeTest.java:20)
```

Example

package a

```
public class Employee {
  protected Date hireDay;
  . . .
}
```

package b

```
public class Department {
  public Date getDate(Employee p){
    return p.hireDay;
  }
}
```

- Valid accesses?

package a

```
public class Department {
  public Date getDate(Employee p) {
    return p.hireDay; ✓
  }
}
```

package b

```
public class Manager extends Employee {
  public Date getDate(){
    return hireDay;   ✓
  }

  public Date getDate(Employee p){
    return p.hireDay;
  }

  public Date getDate(Manager m){
    return m.hireDay; ✓
  }
}
```

```
Manager.java:12: error: hireDay has protected access in Employee
   return p.hireDay;
             ^
1 error
```

What `protected` really means

- Precisely, a `protected` member is accessible
  1. within the class itself
  2. within code in the same package
  3. within code of a subclass through object references that are of at least the same type as the subclass

```
public class Manager extends Employee {
  public Date getDate(){
    return hireDay;
  }

  public Date getDate(Employee p){
    return p.hireDay;
  }

  public Date getDate(Manager m){
    return m.hireDay;
  }
}
```

Object-Oriented (OO) Paradigm

- *Everything* is an object
  - Each object has a state
  - Each object has a type
    - Defines the set of valid operations
- State of application is a graph of objects
- Each class encapsulates the data (fields) and functionality (methods) of the objects.
- When a method is called on an object, *"the object knows what to do on its own."* The caller doesn't need to know what to do.
- Object-Oriented
  - Think what the objects (data) are first
  - Then their functionality (methods)
  - Then how the objects and their functionality can be used to create more complex functionality
    - Reuse code

Software Development - Design Stage

- Characterize classes that model the entities of the domain problem
  1. Fields
  2. Methods
  3. Relationships
- Some classes found to be closely related
  - Factor out common fields, behaviors
  - Design superclasses to store common characteristics
  - Use inheritance to develop subclasses with inherited capabilities
- Makes the code more flexible (see Polymorphism)

Any Problem?

```
public abstract class Animal {
  private String _name;
  private Person _owner;

  public Animal(String n, Person p) {
    _name = n;
    _owner = o;
  }
  public String getName() {
    return _name;
  }
  public abstract void makeNoise();
}
```

```
public class Dog extends Animal {
  private Vacine[] _vacine;

  public Dog(String n, Person p,
             Vacine[] v) {
    super(n, p);
    _vaccine = v;
  }
  public void makeNoise() {
    System.out.println("ão ão");
  }
}
```

Consider the following code:

```
Person p = new Person();
Vacine[] vacines = new Vacine[0];

Animal animal;
Dog dog = new Dog("dog", p, vacines);
dog.makeNoise();
System.out.printf("Nome: %s\n",
                  dog.getName());
animal = dog;
animal.makeNoise();
```

- Any compilation error?
- **No!**
- Any execution error?
- **No!**
- Result of execution:

  Nome: dog
  ão ão
  ão ão
- Previous case is different?
- **No!**

Polymorphism

- Another feature of OOP
- Literally “having many forms”
- Object variables in Java are polymorphic
- Can treat an object of a subclass as an object of its superclass
  - A reference variable of a given type can refer to objects of its own type or to objects of subtypes from its type
- When a method is invoked, which method body is executed?
  - Superclass version or
  - Subclass version

Polymorphism - Code Binding

- Binding: connecting a method call to a method body
- Two kinds of binding
  - Static binding
  - Dynamic binding
- Static binding (Early binding)
  - Binding is performed before the program is run
- Dynamic binding
  - Binding occurs at run time, based on the type of the **object** not on the type of the **variable**
  - Method body to be executed is determined at execution time, not compile time
- Java applies dynamic binding for
  - Non-static, non-final and non-private methods
  - Designated as polymorphic
- Java applies static binding for static methods and private or final non-static methods

Method Lookup

- To determine if a method is legal the compiler looks in the class based on the declared type
  - if it finds it great, if not go to the super class and look there
  - continue until the method is found, or the Object class is reached and the method was never found. (Compile error)
- To determine which polymorphic method is actually executed by the run time system
  - starts with the actual run time **class of the object** that is calling the method
  - search the class for that method
  - if found, execute it, otherwise go to the super class and keep looking
  - repeat until a version is found

Attendance Question

What is output by the code to the right when run?

A. `!!live`

B. `!eggegg`

C. `!egglive`

D. `!!!`

E. `eggegglive`

```
public class Animal{
  public String bt(){ return "!"; }
}

public class Mammal extends Animal{
  public String bt(){ return "live"; }
}

public class Platypus extends Mammal{
  public String bt(){ return "egg";}
}

public static void main(String args[]) {
  Animal a1 = new Animal();
  Animal a2 = new Platypus();
  Mammal m1 = new Platypus();

  System.out.print( a1.bt() );
  System.out.print( a2.bt() );
  System.out.print( m1.bt() );
}
```

Why Bother with Inheritance?

- Inheritance allows programs to model relationships in the real world
  - if the program follows the model it may be easier to write
- Inheritance allows code reuse
  - complete programs faster (especially large programs)
- Polymorphism allows code reuse in another way
  - Assign multiple meanings to the same method name
- Inheritance and polymorphism allow programmers to create *generic algorithms*

@Override Annotation

- Use **@Override** annotation every time a method is overridden

```
class ParentClass {

    public void displayMethod(String msg) {
      System.out.println(msg);
    }
}
```

```
class Subclass extends ParentClass {

  @Override
  public void displayMethod(String msg) {
    System.out.println("Message is: "+ msg);
  }
}
```

- Advantages:
  - If programmer makes a mistake (wrong name or wrong parameter list) and method is not overriden, compiler gives error
  - Improves readability of the code

Subclasses and Superclass Contract

- Polymorphism implies that you can make code that is client of a given type
  - public void printAll(Animal[] animals) { … }
- and that code works well with instances of that type and instances of subtypes of that type
- This requires that subtypes must respect the contract of the superclass
  - The semantic of each overridden method is preserved
  - Each overridden method has an equal or less restricted access modifier
    - A public method of the superclass cannot be overridden as protected
    - But a protected method of the superclass can be overridden as public
- Otherwise, *is-a* relationship would be broken

Polymorphism (continued)

- Operator `instanceof` - determines whether a reference variable that references an object of a particular type

- Example:

```
p instanceof BoxShape
```

- Evaluates to a boolean
  true if p refers an object of the class *BoxShape*
  false otherwise

- Should be **avoided**
  - Usually, it is not OOP

Design Hints for Inheritance

1. Place common operations and fields in the superclass
2. Try not to use `protected` fields
3. Use inheritance to model a Is-A relationship
4. Respect the contract of the superclass
   1. Don't use inheritance unless all inherited methods make sense
   2. Don't change the expected behavior when you override a method
5. Use polymorphism, not type information

```
if (x instanceof Type1)
        ((Type1)x).action1();
else if (x instanceof Type2)
        ((Type2)x).action2();
```

- Solution?

  Do action1 and action2 represent a common concept? If it is, make the concept a method of a common superclass or interface of both types, and then you can simply call `x.action()`.