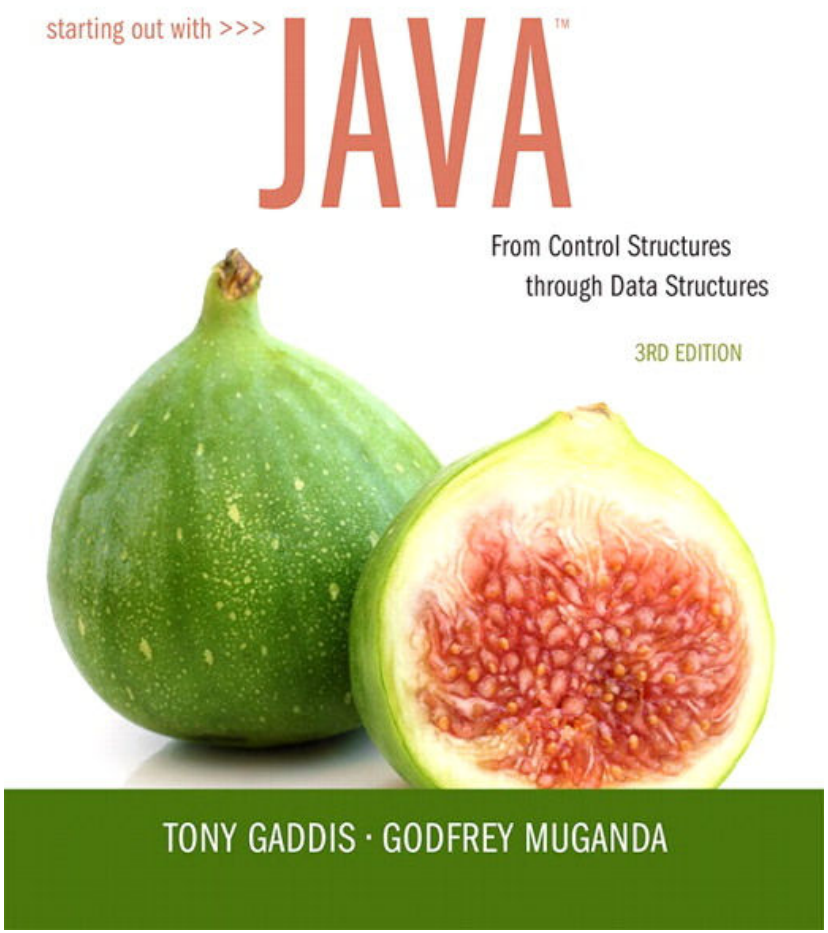
CHAPTER 10

Inheritance



Chapter Topics

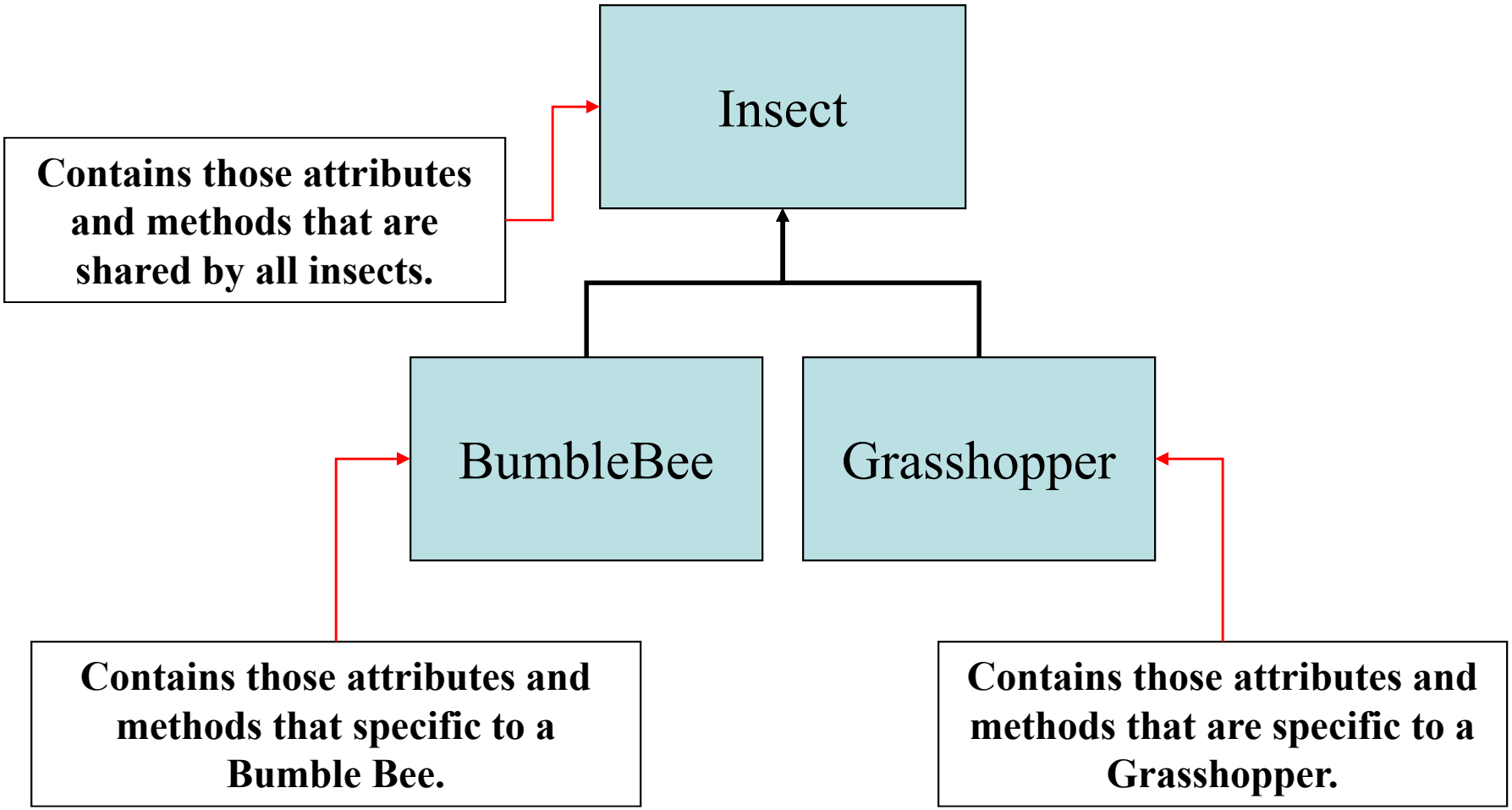
Chapter 10 discusses the following main topics:

- What Is Inheritance?
- Calling the Superclass Constructor
- Overriding Superclass Methods
- Protected Members
- Chains of Inheritance
- The `Object` Class
- Polymorphism
- Abstract Classes and Abstract Methods
- Interfaces
- Anonymous Classes
- Functional Interfaces and Lambda Expressions

What is Inheritance?
Generalization vs. Specialization

- Real-life objects are typically specialized versions of other more general objects.
- The term “insect” describes a very general type of creature with numerous characteristics.
- Grasshoppers and bumblebees are insects
  - They share the general characteristics of an insect.
  - However, they have special characteristics of their own.
    - grasshoppers have a jumping ability, and
    - bumblebees have a stinger.
- Grasshoppers and bumblebees are specialized versions of an insect.

Inheritance



The “is a” Relationship

- The relationship between a superclass and an inherited class is called an “is a” relationship.
  - A grasshopper “is a” insect.
  - A poodle “is a” dog.
  - A car “is a” vehicle.
- A specialized object has:
  - all of the characteristics of the general object, plus
  - additional characteristics that make it special.
- In object-oriented programming, *inheritance* is used to create an “is a” relationship among classes.

The “is a” Relationship

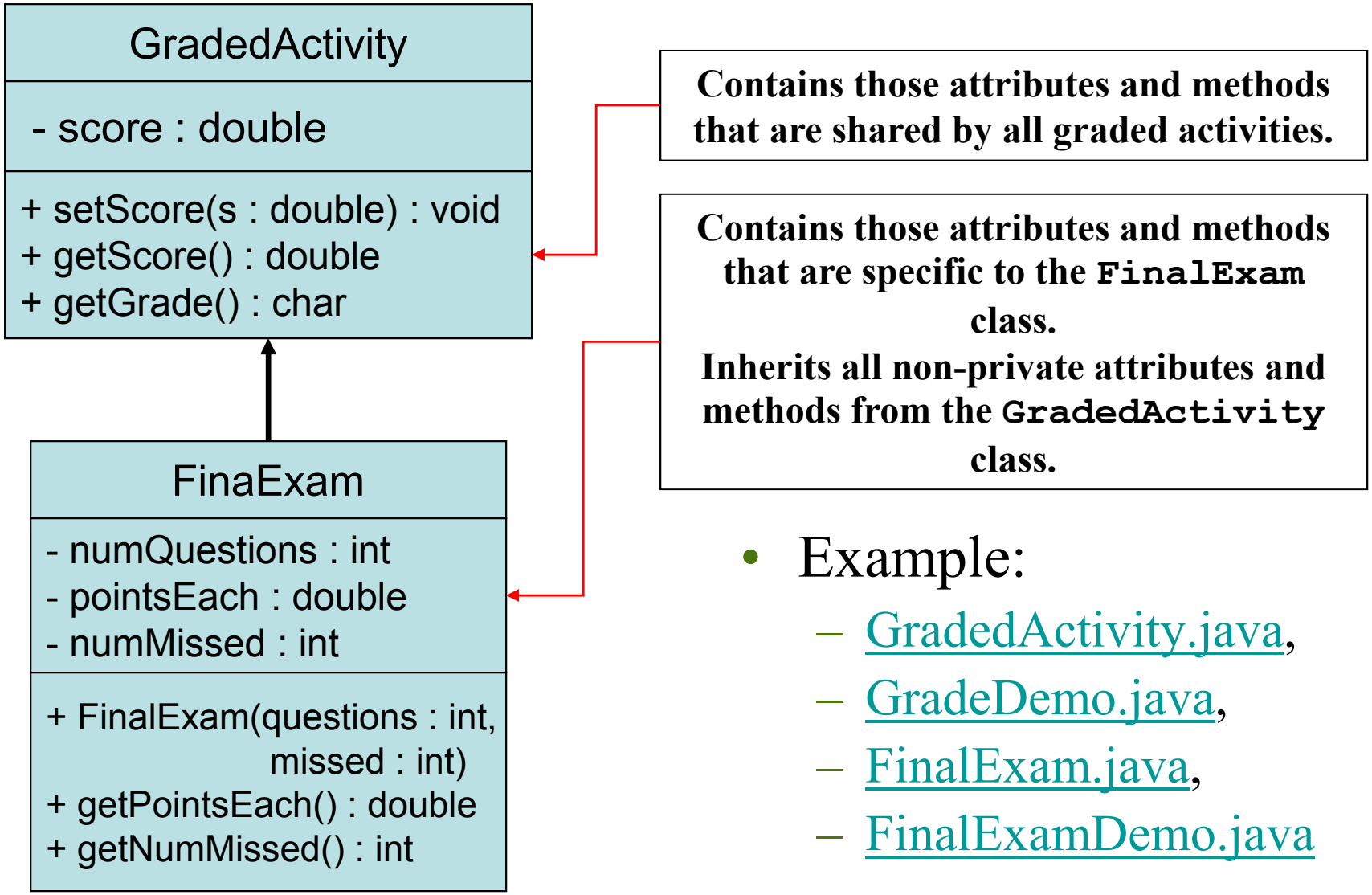
- We can *extend* the capabilities of a class.
- Inheritance involves a superclass and a subclass.
  - The *superclass* is the general class and
  - the *subclass* is the specialized class.
- The subclass is based on, or extended from, the superclass.
  - Superclasses are also called *base classes*, and
  - subclasses are also called *derived classes*.
- The relationship of classes can be thought of as *parent classes* and *child classes*.

Inheritance

- The subclass inherits fields and methods from the superclass without any of them being rewritten.
- New fields and methods may be added to the subclass.
- The Java keyword, *extends*, is used on the class header to define the subclass.

```
public class FinalExam extends GradedActivity
```

The `GradedActivity` Example



- Example:
  - GradedActivity.java,
  - GradeDemo.java,
  - FinalExam.java,
  - FinalExamDemo.java

Inheritance, Fields and Methods

- Members of the superclass that are marked *private*:
  - are not inherited by the subclass,
  - exist in memory when the object of the subclass is created
  - may only be accessed from the subclass by public methods of the superclass.
- Members of the superclass that are marked *public*:
  - are inherited by the subclass, and
  - may be directly accessed from the subclass.

Inheritance, Fields and Methods

- When an instance of the subclass is created, the non-private methods of the superclass are available through the subclass object.

```
FinalExam exam = new FinalExam();
exam.setScore(85.0);
System.out.println("Score = "
                   + exam.getScore());
```

- Non-private methods and fields of the superclass are available in the subclass.

```
setScore(newScore);
```

Inheritance and Constructors

- Constructors are not inherited.
- When a subclass is instantiated, the superclass default constructor is executed first.
- Example:
  - SuperClass1.java
  - SubClass1.java
  - ConstructorDemo1.java

The Superclass's Constructor

- The `super` keyword refers to an object's superclass.
- The superclass constructor can be explicitly called from the subclass by using the `super` keyword.
- Example:
  - SuperClass2.java, SubClass2.java, ConstructorDemo2.java
  - Rectangle.java, Cube.java, CubeDemo.java

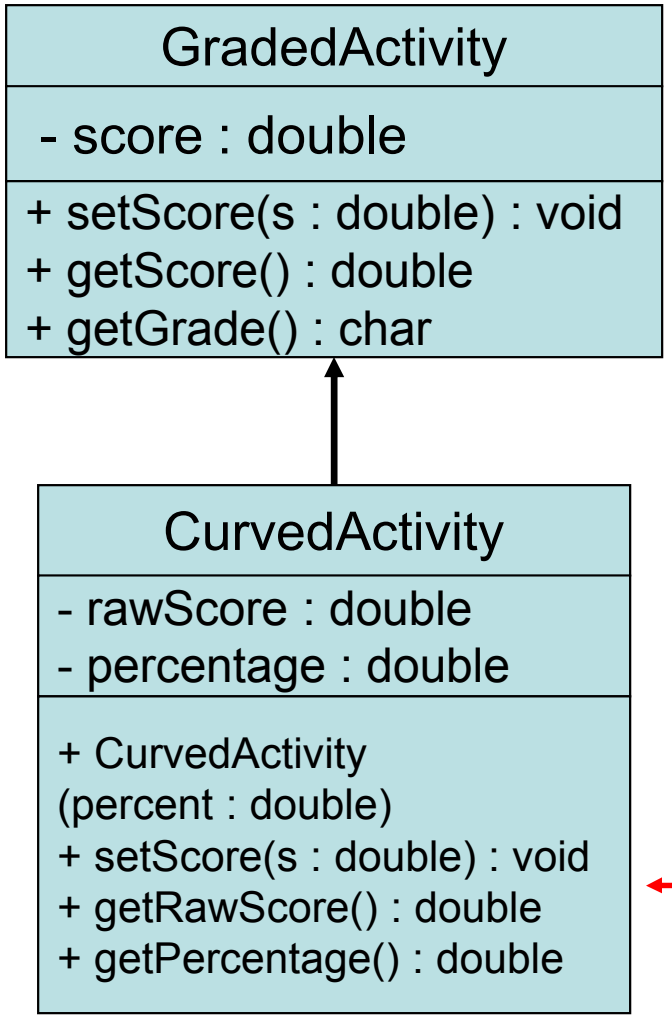
Calling The Superclass Constructor

- If a parameterized constructor is defined in the superclass,
  - the superclass must provide a no-arg constructor, or
    - subclasses must provide a constructor, and
    - subclasses must call a superclass constructor.
- Calls to a superclass constructor must be the first java statement in the subclass constructors.

Overriding Superclass Methods

- A subclass may have a method with the same signature as a superclass method.
- The subclass method overrides the superclass method.
- This is known as *method overriding*.
- Example:
  - GradedActivity.java, CurvedActivity.java, CurvedActivityDemo.java

Overriding Superclass Methods



This method is a more specialized version of the `setScore` method in the superclass, `GradedActivity`.

Overriding Superclass Methods

- Recall that a method's *signature* consists of:
  - the method's name
  - the data types method's parameters in the order that they appear.
- A subclass method that overrides a superclass method must have the same signature as the superclass method.
- An object of the subclass invokes the subclass's version of the method, not the superclass's.
- The `@Override` annotation should be used just before the subclass method declaration.
  - This causes the compiler to display a error message if the method fails to correctly override a method in the superclass.

Overriding Superclass Methods

- An subclass method can call the overridden superclass method via the super keyword.

```
super.setScore(rawScore * percentage);
```

- There is a distinction between overloading a method and overriding a method.
- Overloading is when a method has the same name as one or more other methods, but with a different signature.
- When a method overrides another method, however, they both have the same signature.

Overriding Superclass Methods

- Both overloading and overriding can take place in an inheritance relationship.
- Overriding can only take place in an inheritance relationship.
- Example:
  - SuperClass3.java,
  - SubClass3.java,
  - ShowValueDemo.java

Preventing a Method from Being Overridden

- The `final` modifier will prevent the overriding of a superclass method in a subclass.

```
public final void message()
```

- If a subclass attempts to override a final method, the compiler generates an error.
- This ensures that a particular superclass method is used by subclasses rather than a modified version of it.

Protected Members

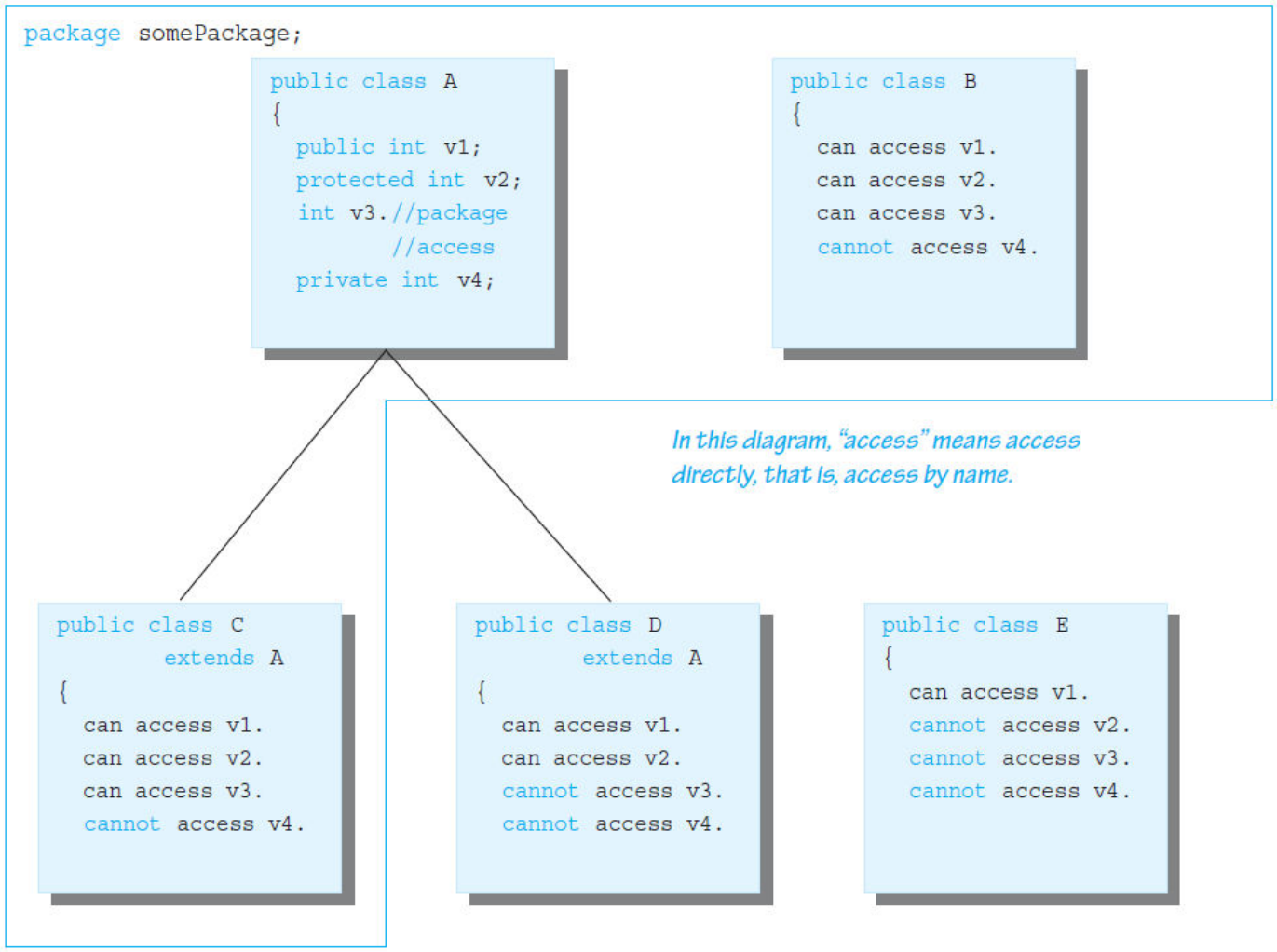
- Protected members of class:
  - may be accessed by methods in a subclass, and
  - by methods in the same package as the class.
- Java provides a third access specification, `protected`.
- A *protected* member's access is somewhere between *private* and *public*.
- Example:
  - GradedActivity2.java
  - FinalExam2.java
  - ProtectedDemo.java

Protected Members

- Using `protected` instead of `private` makes some tasks easier.
- However, any class that is derived from the class, or is in the same package, has unrestricted access to the protected member.
- It is always better to make all fields `private` and then provide `public` methods for accessing those fields.
- If no access specifier for a class member is provided, the class member is given *package access* by default.
- Any method in the same package may access the member.

Access Modifiers

Display 7.9 Access Modifiers



Access Specifiers

Access Modifier	Accessible to a subclass inside the same package?	Accessible to all other classes inside the same package?
default (no modifier)	Yes	Yes
Public	Yes	Yes
Protected	Yes	Yes
Private	No	No

Access Modifier	Accessible to a subclass outside the package?	Accessible to all other classes outside the package?
default (no modifier)	No	No
Public	Yes	Yes
Protected	Yes	No
Private	No	No

Tip: Static Variables Are Inherited

- Static variables in a base class are inherited by any of its derived classes
- The modifiers **`public`**, **`private`**, and **`protected`**, and package access have the same meaning for static variables as they do for instance variables

Access to a Redefined Base Method

- Within the definition of a method of a derived class, the base class version of an overridden method of the base class can still be invoked
  - Simply preface the method name with super and a dot

```
public String toString()
{
  return (super.toString() + "$" + wageRate);
}
```

- However, using an object of the derived class outside of its class definition, there is no way to invoke the base class version of an overridden method

You Cannot Use Multiple `supers`

- It is only valid to use **`super`** to invoke a method from a direct parent
  - Repeating **`super`** will not invoke a method from some other ancestor class
- For example, if the **`Employee`** class were derived from the class **`Person`**, and the **`HourlyEmployee`** class were derived form the class **`Employee`** , it would not be possible to invoke the **`toString`** method of the **`Person`** class within a method of the **`HourlyEmployee`** class

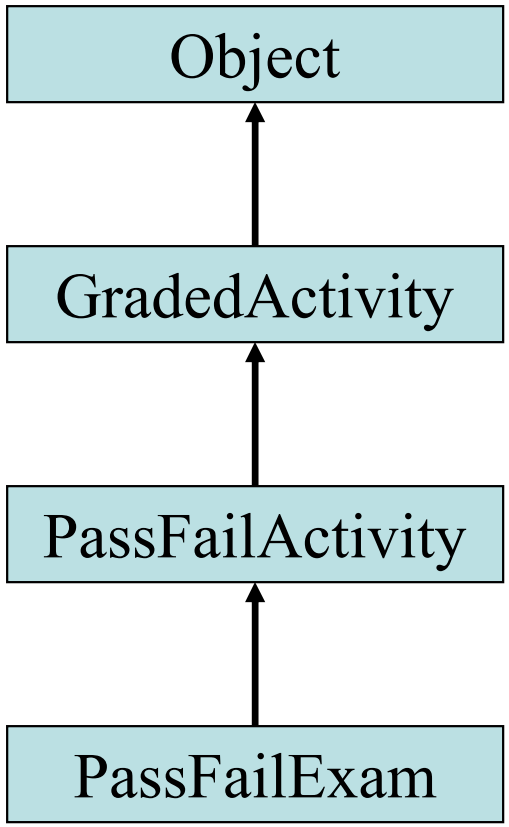
```
super.super.toString() // ILLEGAL!
```

Chains of Inheritance

- A superclass can also be derived from another class.

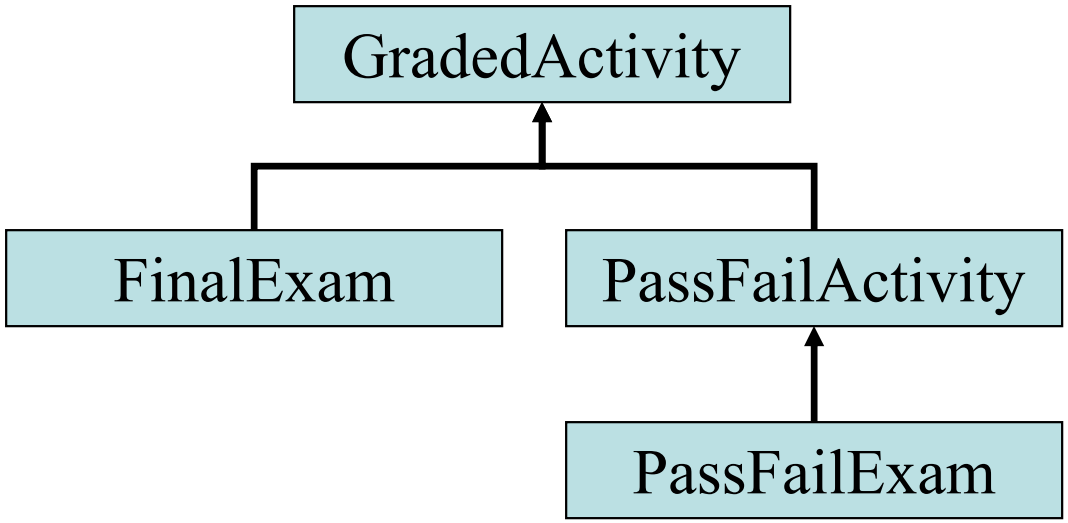
Example:

GradedActivity.java
PassFailActivity.java
PassFailExam.java
PassFailExamDemo.java



Chains of Inheritance

- Classes often are depicted graphically in a *class hierarchy*.
- A class hierarchy shows the inheritance relationships between classes.



You Cannot Use Multiple `supers`

- It is only valid to use **`super`** to invoke a method from a direct parent
  - Repeating **`super`** will not invoke a method from some other ancestor class
- For example, if the **`Employee`** class were derived from the class **`Person`**, and the **`HourlyEmployee`** class were derived form the class **`Employee`** , it would not be possible to invoke the **`toString`** method of the **`Person`** class within a method of the **`HourlyEmployee`** class

```
super.super.toString() // ILLEGAL!
```

The Class `Object`

- In Java, every class is a descendent of the class ***`Object`***
  - Every class has **`Object`** as its ancestor
  - Every object of every class is of type **`Object`**, as well as being of the type of its own class
- If a class is defined that is not explicitly a derived class of another class, it is still automatically a derived class of the class **`Object`**

The Class `Object`

- The class `Object` is in the package `java.lang` which is always imported automatically
- Having an `Object` class enables methods to be written with a parameter of type `Object`
  - A parameter of type `Object` can be replaced by an object of any class whatsoever
  - For example, some library methods accept an argument of type `Object` so they can be used with an argument that is an object of any class

The Class `Object`

- The class **`Object`** has some methods that every Java class inherits
  - For example, the **`equals`** and **`toString`** methods
- Every object inherits these methods from some ancestor class
  - Either the class **`Object`** itself, or a class that itself inherited these methods (ultimately) from the class **`Object`**
- However, these inherited methods should be overridden with definitions more appropriate to a given class
  - Some Java library classes assume that every class has its own version of such methods

The Right Way to Define `equals`

- Since the `equals` method is always inherited from the class `Object`, methods like the following simply overload it:

```
public boolean equals(Employee otherEmployee)
{ . . . }
```

- However, this method should be overridden, not just overloaded:

```
public boolean equals(Object otherObject)
{ . . . }
```

The Right Way to Define `equals`

- The overridden version of **`equals`** must meet the following conditions
  - The parameter **`otherObject`** of type **`Object`** must be type cast to the given class (e.g., **`Employee)`**
  - However, the new method should only do this if **`otherObject`** really is an object of that class, and if **`otherObject`** is not equal to **`null`**
  - Finally, it should compare each of the instance variables of both objects

A Better `equals` Method for the Class `Employee`

```
public boolean equals(Object otherObject)
{
  if(otherObject == null)
    return false;
  else if(getClass( ) != otherObject.getClass( ))
    return false;
  else
  {
    Employee otherEmployee = (Employee)otherObject;
    return (name.equals(otherEmployee.name) &&
      hireDate.equals(otherEmployee.hireDate));
  }
}
```

Tip: `getClass` Versus `instanceof`

- Many authors suggest using the **`instanceof`** operator in the definition of **`equals`**
  - Instead of the **`getClass()`** method
- The **`instanceof`** operator will return **`true`** if the object being tested is a member of the class for which it is being tested
  - However, it will return **`true`** *if it is a descendent of that class* as well
- It is possible (and especially disturbing), for the **`equals`** method to behave inconsistently given this scenario

Tip: `getClass` Versus `instanceof`

- **`testH`** will be **`true`**, because **`h`** is an **`Employee`** with the same name and hire date as **`e`**
- However, **`testE`** will be **`false`**, because **`e`** is not an **`HourlyEmployee`**, and cannot be compared to **`h`**
- Note that this problem would not occur if the **`getClass()`** method were used instead, as in the previous **`equals`** method example

`instanceof` and `getClass`

- Both the `instanceof` operator and the `getClass()` method can be used to check the class of an object
- However, the `getClass()` method is more exact
  - The `instanceof` operator simply tests the class of an object
  - The `getClass()` method used in a test with `==` or `!=` tests if two objects *were created with* the same class

The `instanceof` Operator

- The **`instanceof`** operator checks if an object is of the type given as its second argument

```
Object instanceof ClassName
```

  - This will return **`true`** if **`Object`** is of type **`ClassName`**, and otherwise return **`false`**
  - Note that this means it will return **`true`** if **`Object`** is the type of *any descendent class* of **`ClassName`**

The `getClass()` Method

- Every object inherits the same **`getClass()`** method from the **`Object`** class
  - This method is marked **`final`**, so it cannot be overridden
- An invocation of **`getClass()`** on an object returns a representation *only* of the class that was used with **`new`** to create the object
  - The results of any two such invocations can be compared with **`==`** or **`!=`** to determine whether or not they represent the exact same class

```
(object1.getClass() == object2.getClass())
```

Polymorphism

Polymorphism

- A reference variable can reference objects of classes that are derived from the variable's class.

```
GradedActivity exam;
```

- We can use the exam variable to reference a `GradedActivity` object.

```
exam = new GradedActivity();
```

- The `GradedActivity` class is also used as the superclass for the `FinalExam` class.
- An object of the `FinalExam` class ***is a*** `GradedActivity` object.

Polymorphism

- A `GradedActivity` variable can be used to reference a `FinalExam` object.

```
GradedActivity exam = new FinalExam(50, 7);
```

- This statement creates a `FinalExam` object and stores the object's address in the exam variable.
- This is an example of polymorphism.
- The term *polymorphism* means the ability to take many forms.
- In Java, a reference variable is *polymorphic* because it can reference objects of types different from its own, as long as those types are subclasses of its type.

Polymorphism

- Other legal polymorphic references:

```
GradedActivity exam1 = new FinalExam(50, 7);
GradedActivity exam2 = new PassFailActivity(70);
GradedActivity exam3 = new PassFailExam(100, 10, 70);
```

- The `GradedActivity` class has three methods: `setScore`, `getScore`, and `getGrade`.
- A `GradedActivity` variable can be used to call only those three methods.

```
GradedActivity exam = new PassFailExam(100, 10, 70);
System.out.println(exam.getScore()); // This works.
System.out.println(exam.getGrade()); // This works.
System.out.println(exam.getPointsEach()); // ERROR!
```

Late (Dynamic) Binding

- The process of associating a method definition with a method invocation is called *binding*
- If the method definition is associated with its invocation when the code is compiled, that is called *early binding*
- If the method definition is associated with its invocation when the method is invoked (at run time), that is called *late binding* or *dynamic binding*

Late (Dynamic) Binding

- Java uses late binding for all methods (except private, `final`, and static methods)
- Because of late binding, a method can be written in a base class to perform a task, even if portions of that task aren't yet defined

Polymorphism and Dynamic Binding

- If the object of the subclass has overridden a method in the superclass:
  - If the variable makes a call to that method the subclass's version of the method will be run.

```
GradedActivity exam = new PassFailActivity(60);
exam.setScore(70);
System.out.println(exam.getGrade());
```

- Java performs *dynamic binding* or *late binding* when a variable contains a polymorphic reference.
- The Java Virtual Machine determines at runtime which method to call, depending on the type of object that the variable references.

Polymorphism

- It is the object's type, rather than the reference type, that determines which method is called.
- Example:
  - Polymorphic.java
- You cannot assign a superclass object to a subclass reference variable.

The `final` Modifier

- A *method* marked **`final`** indicates that it cannot be overridden with a new definition in a derived class
  - If **`final`**, the compiler can use early binding with the method

```
public final void someMethod() { . . . }
```

- A *class* marked **`final`** indicates that it cannot be used as a base class from which to derive any other classes

Upcasting and Downcasting

- *Upcasting* is when an object of a derived class is assigned to a variable of a base class (or any ancestor class)

```
Sale saleVariable; //Base class
DiscountSale discountVariable = new
    DiscountSale("paint", 15,10); //Derived class
saleVariable = discountVariable; //Upcasting
System.out.println(saleVariable.toString());
```

- Because of late binding, **`toString`** above uses the definition given in the **`DiscountSale`** class

Upcasting and Downcasting

- *Downcasting* is when a type cast is performed from a base class to a derived class (or from any ancestor class to any descendent class)
  - Downcasting has to be done very carefully
  - In many cases it doesn't make sense, or is illegal:

```
discountVariable =                    //will produce
     (DiscountSale)saleVariable;//run-time error
discountVariable = saleVariable //will produce
                                      //compiler error
```

  - There are times, however, when downcasting is necessary, e.g., inside the **`equals`** method for a class:

```
Sale otherSale = (Sale)otherObject;//downcasting
```

Pitfall: Downcasting

- It is the responsibility of the programmer to use downcasting only in situations where it makes sense
  - The compiler does not check to see if downcasting is a reasonable thing to do
- Using downcasting in a situation that does not make sense usually results in a run-time error

Tip: Checking to See if Downcasting is Legitimate

- Downcasting to a specific type is only sensible if the object being cast is an instance of that type
  - This is exactly what the **`instanceof`** operator tests for:

    `object` **`instanceof`** ***`ClassName`***
  - It will return true if ***`object`*** is of type ***`ClassName`***
  - In particular, it will return true if ***`object`*** is an instance of any descendent class of ***`ClassName`***

A First Look at the `clone` Method

- Every object inherits a method named **`clone`** from the class **`Object`**
  - The method **`clone`** has no parameters
  - It is supposed to return a deep copy of the calling object
- However, the inherited version of the method was not designed to be used as is
  - Instead, each class is expected to override it with a more appropriate version

A First Look at the `clone` Method

- The heading for the **`clone`** method defined in the **`Object`** class is as follows:

```
protected Object clone()
```

- The heading for a **`clone`** method that overrides the **`clone`** method in the **`Object`** class can differ somewhat from the heading above
  - A change to a more permissive access, such as from protected to public, is always allowed when overriding a method definition
  - Changing the return type from **`Object`** to the type of the class being cloned is allowed because every class is a descendent class of the class **`Object`**
  - This is an example of a covariant return type

A First Look at the `clone` Method

- If a class has a copy constructor, the **`clone`** method for that class can use the *copy constructor* to create the copy returned by the **`clone`** method

```
public Sale clone()
{
  return new Sale(this);
}
```

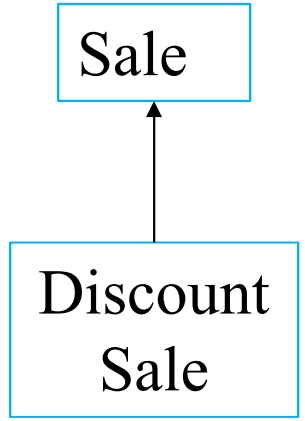
and another example:

```
public DiscountSale clone()
{
  return new DiscountSale(this);
}
```

Pitfall: Limitations of Copy Constructors

- Although the copy constructor and **`clone`** method for a class appear to do the same thing, there are cases where only a **`clone`** will work
- For example, given a method **`badcopy`** in the class **`Sale`** that copies an array of sales

```
public static Sale[] badCopy(Sale[] a)
   {
      Sale[] b = new Sale[a.length];
      for (int i = 0; i < a.length; i++)
         b[i] = new Sale(a[i]);  //Problem here!
      return b;
   }
```



Pitfall: Limitations of Copy Constructors

- However, if the **`clone`** method is used instead of the copy constructor, then (because of late binding) a true copy is made, even from objects of a derived class (e.g., **`DiscountSale`**):

```
b[i] = (a[i].clone());//DiscountSale object
```

  - The reason this works is because the method **`clone`** has the same name in all classes, and polymorphism works with method names
  - The copy constructors named **`Sale`** and **`DiscountSale`** have different names, and polymorphism doesn't work with methods of different names

```
public static Sale[] badCopy(Sale[] a)
  {
     Sale[] b = new Sale[a.length];
     for (int i = 0; i < a.length; i++)
        b[i] = a[i].clone();
     return b;
  }
```

Abstract Classes

- An abstract class cannot be instantiated, but other classes are derived from it.
- An *Abstract class* serves as a superclass for other classes.
- The abstract class represents the generic or abstract form of all the classes that are derived from it.
- A class becomes abstract when you place the abstract key word in the class definition.

```
public abstract class ClassName
```

- A class that has no abstract methods is called a *concrete class*

Abstract Methods

- An abstract method has no body and must be overridden in a subclass.
- An *abstract method* is a method that appears in a superclass, but expects to be overridden in a subclass.
- An abstract method has only a header and no body.

```
AccessSpecifier abstract ReturnType MethodName(ParameterList);
```

- Example:
  - Student.java, CompSciStudent.java, CompSciStudentDemo.java

Abstract Methods

- Notice that the key word `abstract` appears in the header, and that the header ends with a semicolon.

```
public abstract void setValue(int value);
```

- Any class that contains an abstract method is automatically abstract.
- If a subclass fails to override an abstract method, a compiler error will result.
- Abstract methods are used to ensure that a subclass implements the method.

Pitfall: You Cannot Create Instances of an Abstract Class

- An abstract class can only be used to derive more specialized classes
  - While it may be useful to discuss employees in general, in reality an employee must be a salaried worker or an hourly worker
- An abstract class constructor cannot be used to create an object of the abstract class
  - However, a derived class constructor will include an invocation of the abstract class constructor in the form of **`super`**

Tip: An Abstract Class Is a Type

- Although an object of an abstract class cannot be created, it is perfectly fine to have a parameter of an abstract class type
  - This makes it possible to plug in an object of any of its descendent classes
- It is also fine to use a variable of an abstract class type, as long is it names objects of its concrete descendent classes only

Interfaces

- An *interface* is similar to an abstract class that has all abstract methods.
  - It cannot be instantiated, and
  - all of the methods listed in an interface must be written elsewhere.
- The purpose of an interface is to specify behavior for other classes.
- It is often said that an interface is like a "contract," and when a class implements an interface it must adhere to the contract.
- An interface looks similar to a class, except:
  - the keyword `interface` is used instead of the keyword `class`, and
  - the methods that are specified in an interface have no bodies, only headers that are terminated by semicolons.

Interfaces

- The general format of an interface definition:

```
public interface InterfaceName
{
   (Method headers...)
}
```

- All methods specified by an interface are public by default.
- A class can implement one or more interfaces.

Interfaces

- If a class implements an interface, it uses the `implements` keyword in the class header.

```
public class FinalExam3 extends GradedActivity
  implements Relatable
```

- Example:
  - GradedActivity.java
  - Relatable.java
  - FinalExam3.java
  - InterfaceDemo.java

Fields in Interfaces

- An interface can contain field declarations:
  - all fields in an interface are treated as `final` and `static`.
- Because they automatically become `final`, you must provide an initialization value.

```
public interface Doable
{
   int FIELD1 = 1, FIELD2 = 2;
   (Method headers...)
}
```

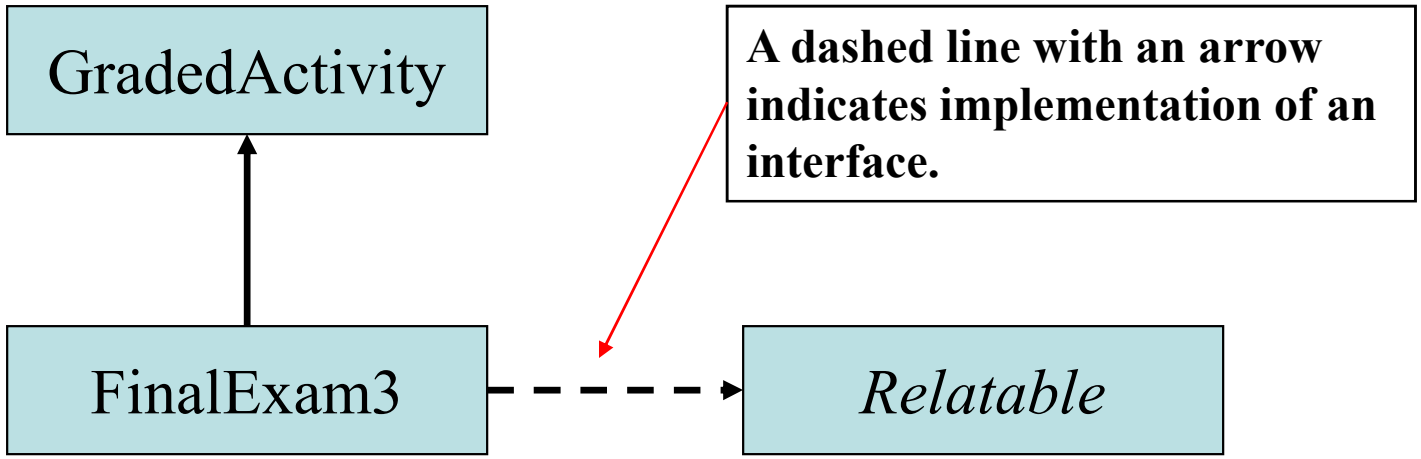
- In this interface, `FIELD1` and `FIELD2` are `final static int` variables.
- Any class that implements this interface has access to these variables.

Implementing Multiple Interfaces

- A class can be derived from only one superclass.
- Java allows a class to implement multiple interfaces.
- When a class implements multiple interfaces, it must provide the methods specified by all of them.
- To specify multiple interfaces in a class definition, simply list the names of the interfaces, separated by commas, after the implements key word.

```
public class MyClass implements Interface1,
                                 Interface2,
                                 Interface3
```

Interfaces in UML



Polymorphism with Interfaces

- Java allows you to create reference variables of an interface type.
- An interface reference variable can reference any object that implements that interface, regardless of its class type.
- This is another example of polymorphism.
- Example:
  - RetailItem.java
  - CompactDisc.java
  - DvdMovie.java
  - PolymorphicInterfaceDemo.java

Polymorphism with Interfaces

- In the example code, two `RetailItem` reference variables, `item1` and `item2`, are declared.
- The `item1` variable references a `CompactDisc` object and the `item2` variable references a `DvdMovie` object.
- When a class implements an interface, an inheritance relationship known as *interface inheritance* is established.
  - a `CompactDisc` object *is a* `RetailItem`, and
  - a `DvdMovie` object *is a* `RetailItem`.

Polymorphism with Interfaces

- A reference to an interface can point to any class that implements that interface.
- You cannot create an instance of an interface.

```
RetailItem item = new RetailItem(); // ERROR!
```

- When an interface variable references an object:
  - only the methods declared in the interface are available,
  - explicit type casting is required to access the other methods of an object referenced by an interface reference.

Default Methods

- Beginning in Java 8, interfaces may have *default methods*.
- A default method is an interface method that has a body.
- You can add new methods to an existing interface without causing errors in the classes that already implement the interface.

- Example:
  - Displayable.java
  - Person.java
  - InterfaceDemoDefaultMethod.java

Anonymous Inner Classes

- An inner class is a class that is defined inside another class.
- An anonymous inner class is an inner class that has no name.
- An anonymous inner class must implement an interface, or extend another class.
- Useful when you need a class that is simple, and to be instantiated only once in your code.

- Example:
  - IntCalculator.java
  - AnonymousClassDemo.java

Functional Interfaces and Lambda Expressions

- A functional interface is an interface that has one abstract method.
- A lambda expression can be used to create an object that implements the interface, and overrides its abstract method.
- In Java 8, these features work together to simplify code, particularly in situations where you might use anonymous inner classes.

- Example:
  - LambdaDemo.java
  - LambdaDemo2.java