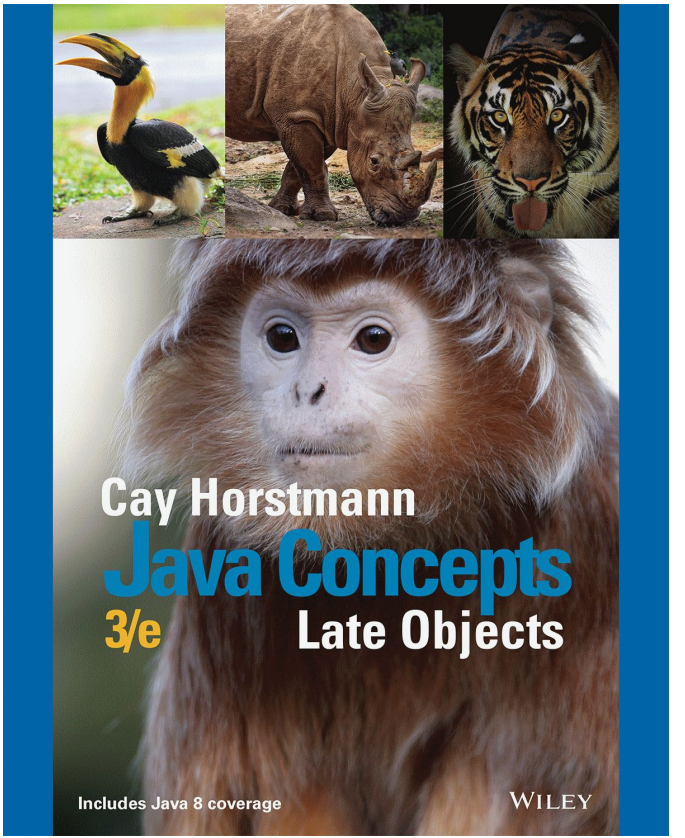
Chapter 9 – Inheritance and Interfaces

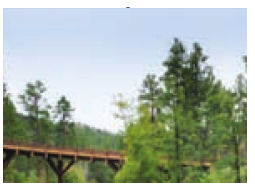


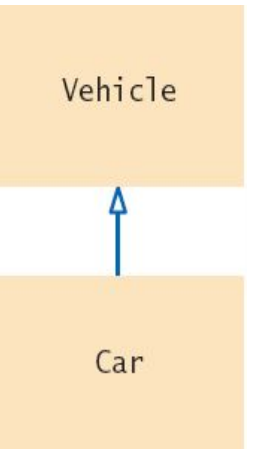
Chapter Goals

- To learn about inheritance
- To implement subclasses that inherit and override superclass methods
- To understand the concept of polymorphism
- To understand the common superclass `Object` and its methods
- To work with interface types

Inheritance Hierarchies

- In object-oriented programming, inheritance is a relationship between:
  - A *superclass*: a more generalized class
  - A *subclass*: a more specialized class





- The subclass 'inherits' data (variables) and behavior (methods) from the superclass

A Vehicle Class Hierarchy

- General
- Specialized
- More Specific

Vehicle

Motorcycle

Car

Truck

Sedan

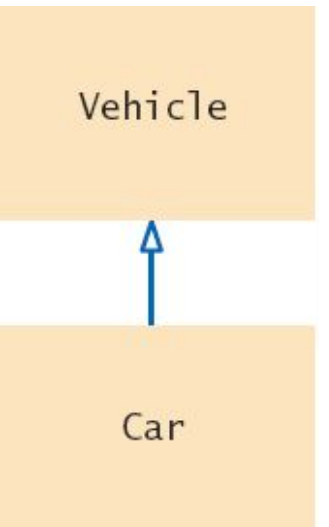
SUV

The Substitution Principle

- Since the subclass Car "**is-a**" Vehicle
- Car shares common traits with Vehicle
- You can substitute a Car object in an algorithm that expects a Vehicle object

```
Car myCar = new Car(. . .);
processVehicle(myCar);
```

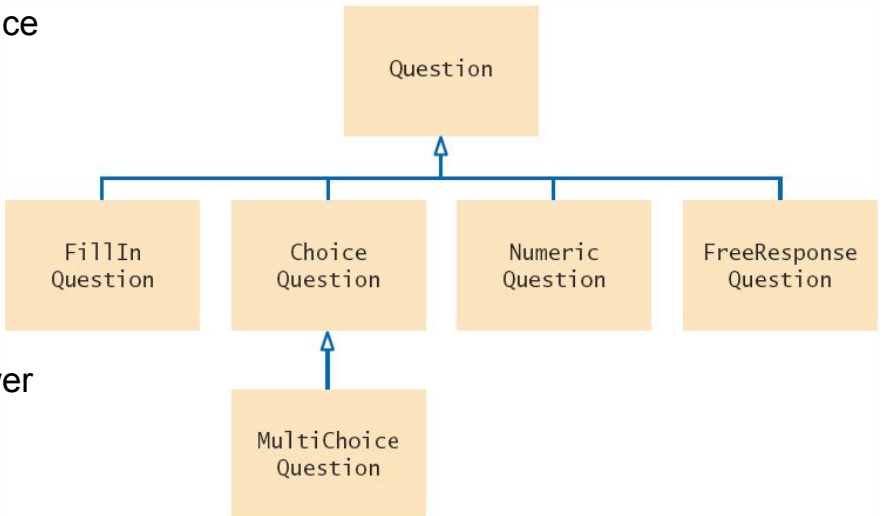
The 'is-a' relationship is represented by an arrow in a class diagram and means that the subclass can behave as an object of the superclass.



Quiz Question Hierarchy

- There are different types of quiz questions:
  1) Fill-in-the-blank
  2) Single answer choice
  3) Multiple answer choice
  4) Numeric answer
  5) Free Response

The 'root' of the hierarchy is shown at the top.



- A question can:
  - Display it's text
  - Check for correct answer

Question.java (1)

- Only handles Strings
- No support for:
  - Approximate values
  - Multiple answer choice

```
1  /**
2     A question with a text and an answer.
3  */
4  public class Question
5  {
6     private String text;
7     private String answer;
8
9     /**
10       Constructs a question with empty question and answer.
11    */
12    public Question()
13    {
14       text = "";
15       answer = "";
16    }
17
18    /**
19       Sets the question text.
20       @param questionText the text of this question
21    */
22    public void setText(String questionText)
23    {
24       text = questionText;
25    }
```

The class `Question` is the 'root' of the hierarchy, also known as the superclass.

Question.java (2)

```
27    /**
28       Sets the answer for this question.
29       @param correctResponse the answer
30    */
31    public void setAnswer(String correctResponse)
32    {
33       answer = correctResponse;
34    }
35
36    /**
37       Checks a given response for correctness.
38       @param response the response to check
39       @return true if the response was correct, false otherwise
40    */
41    public boolean checkAnswer(String response)
42    {
43       return response.equals(answer);
44    }
45
46    /**
47       Displays this question.
48    */
49    public void display()
50    {
51       System.out.println(text);
52    }
53 }
```

QuestionDemo1.java

```
1  import java.util.ArrayList;
2  import java.util.Scanner;
3
4  /**
5     This program shows a simple quiz with one question.
6  */
7  public class QuestionDemo1
8  {
9     public static void main(String[] args)
10    {
11       Scanner in = new Scanner(System.in);
12
13       Question q = new Question();
14       q.setText("Who was the inventor of Java?");
15       q.setAnswer("James Gosling");
16
17       q.display();
18       System.out.print("Your answer: ");
19       String response = in.nextLine();
20       System.out.println(q.checkAnswer(response));
21    }
22 }
```

Program Run

```
Who was the inventor of Java?
Your answer: James Gosling
true
```

Creates an object of the `Question` class and uses methods.

Self Check 9.1

Consider classes `Manager` and `Employee`. Which should be the superclass and which should be the subclass?

Answer: Because every manager is an employee but not the other way around, the `Manager` class is more specialized. It is the subclass, and `Employee` is the superclass.

Self Check 9.2

What are the inheritance relationships between classes `BankAccount`, `CheckingAccount`, and `SavingsAccount`?

Answer: `CheckingAccount` and `SavingsAccount` both inherit from the more general class `BankAccount`.

Self Check 9.3

Figure 7.2 shows an inheritance diagram of exception classes in Java. List all superclasses of the class `RuntimeException`.

Answer: `Exception, Throwable`

Self Check 9.4

Consider the method `doSomething(Car c)` . List all vehicle classes from Figure 1 whose objects *cannot* be passed to this method.

Answer: Vehicle, truck, motorcycle

Self Check 9.5

Should a class `Quiz` inherit from the class `Question`? Why or why not?

Answer: It shouldn't. A quiz isn't a question; it *has* questions.

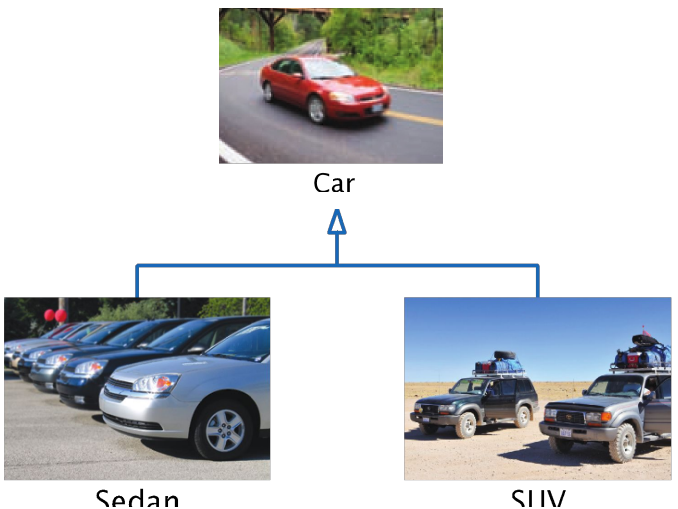
Programming Tip

- Use a Single Class for Variation in Values, Inheritance for Variation in Behavior
  - If two vehicles only vary by fuel efficiency, use an instance variable for the variation, not inheritance

```
// Car instance variable
double milesPerGallon;
```

  - If two vehicles behave differently,
  - use inheritance

Be careful not to over-use inheritance



Implementing Subclasses

- Consider implementing `ChoiceQuestion` to handle:

```
In which country was the inventor of Java born?
1. Australia
2. Canada
3. Denmark
4. United States
```

- How does `ChoiceQuestion` differ from `Question`?
  - It stores choices (1,2,3 and 4) in addition to the question
  - There must be a method for adding multiple choices
    - The display method will show these choices below the question, numbered appropriately

In this section you will see how to form a subclass and how a subclass automatically inherits from its superclass.

Inheriting from the Superclass

- Subclasses inherit from the superclass:
  - All public methods that it does not override
  - All instance variables
- The Subclass can
  - Add new instance variables
  - Add new methods
  - Change the implementation of inherited methods

Form a subclass by specifying what is different from the superclass.

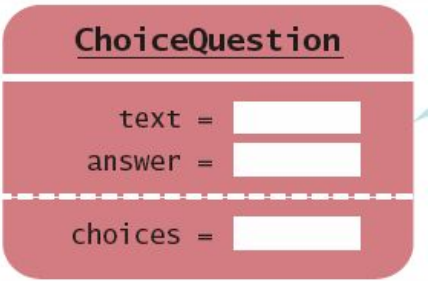
Overriding Superclass Methods

- Can you re-use any methods of the `Question` class?
  - Inherited methods perform exactly the same
  - If you need to change how a method works:
    - Write a new more specialized method in the subclass
    - Use the same method name as the superclass method you want to replace
    - It must take all of the same parameters
  - This will ***override*** the superclass method
- The new method will be invoked with the same method name when it is called on a subclass object

A subclass can override a method of the superclass by providing a new implementation.

Planning the Subclass

- Use the reserved word `extends` to inherit from `Question`
  - Inherits text and answer variables
  - Add new instance variable choices



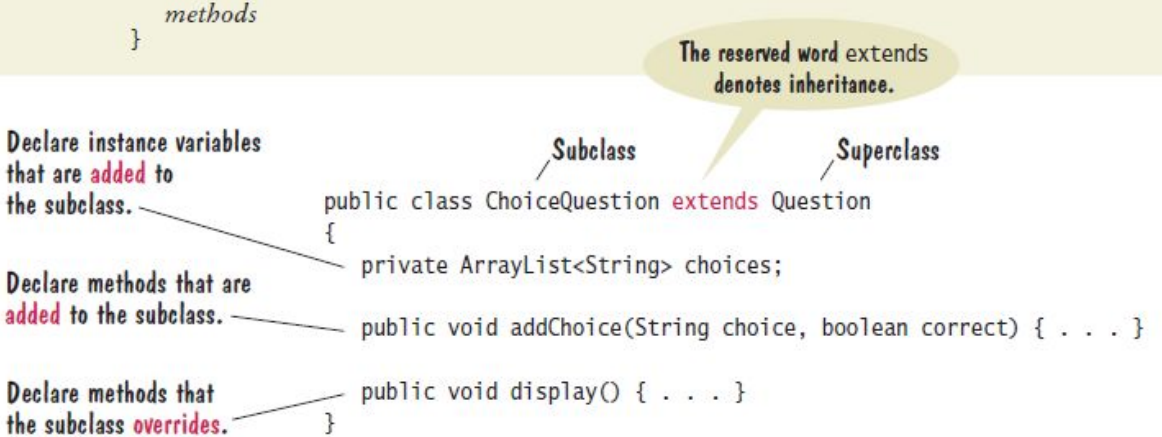

```
public class ChoiceQuestion extends Question
{
   // This instance variable is added to the subclass
   private ArrayList<String> choices;

   // This method is added to the subclass
   public void addChoice(String choice, boolean correct) { . . . }

   // This method overrides a method from the superclass
   public void display() { . . . }
}
```

Syntax 9.1 Subclass Declaration

- The subclass inherits from the superclass and '`extends`' the functionality of the superclass

Syntax

```
public class SubclassName extends SuperclassName
{
   instance variables
   methods
}
```



Implementing addChoice

- The method will receive two parameters
  - The text for the choice
  - A boolean denoting if it is the correct choice or not
- It adds text as a choice, adds choice number to the text and calls the inherited `setAnswer` method

```
public void addChoice(String choice, boolean correct)
{
  choices.add(choice);
  if (correct)
  {
    // Convert choices.size() to string
    String choiceString = "" + choices.size();
    setAnswer(choiceString);
  }
}
```

`setAnswer()` is the same as calling `this.setAnswer()`

Self Check 9.6

Suppose q is an object of the class `Question` and `cq` an object of the class `ChoiceQuestion`. Which of the following calls are legal?

a. `q.setAnswer(response)`
b. `cq.setAnswer(response)`
c. `q.addChoice(choice, true)`
d. `cq.addChoice(choice, true)`

Answer: a, b, d

Self Check 9.7

Suppose the class `Employee` is declared as follows:

```
public class Employee
{
   private String name;
   private double baseSalary;

   public void setName(String newName) { . . . }
   public void setBaseSalary(double newSalary) { . . . }
   public String getName() { . . . }
   public double getSalary() { . . . }
}
```

Declare a class `Manager` that inherits from the class `Employee` and adds an instance variable `bonus` for storing a salary bonus. Omit constructors and methods.

Answer:

```
public class Manager extends Employee
{
   private double bonus;
   // Constructors and methods omitted
}
```

Self Check 9.8

Which instance variables does the `Manager` class from Self Check 7 have?

Answer: `name`, `baseSalary`, and `bonus`

Self Check 9.9

In the `Manager` class, provide the method header (but not the implementation) for a method that overrides the `getSalary` method from the class `Employee`.

Answer:

```
public class Manager extends Employee
{
   . . .
   public double getSalary() { . . . }
}
```

Self Check 9.10

Which methods does the `Manager` class from Self Check 9 inherit?

Answer: `getName, setName, setBaseSalary`

Common Error

- Replicating Instance Variables from the Superclass
  - A subclass cannot directly access private instance variables of the superclass

```
public class Question
{
   private String text;
   private String answer;
   . . .
```

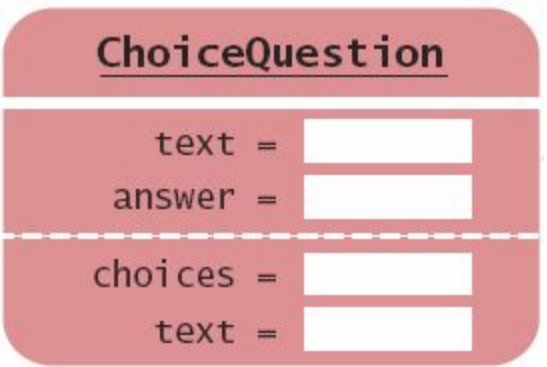
```
public class ChoiceQuestion extends Question
{
   . . .
   text = questionText;   // Complier Error!
```

Common Error (2)

- Do not try to fix the compiler error with a new instance variable of the same name

```
public class ChoiceQuestion extends Question
{
  private String text;  // Second copy
```

- The constructor sets one `text` variable
- The display method outputs the other



Common Error

- Confusing *Super*- and *Sub*classes
  - The use of the terminology super and sub may be confusing
  - The Subclass `ChoiceQuestion` is an 'extended' and more powerful version of `Question`
    - Is it a 'super' version of `Question`?... NO
- Super and Subclass terminology comes from set theory
  - `ChoiceQuestion` is one of a **subset** of all objects that inherit from `Question`
  - The set of `Question` objects is a **superset** of `ChoiceQuestion` objects

Overriding Methods

- The `ChoiceQuestion` class needs a `display` method that overrides the `display` method of the `Question` class
- They are two different method implementations
- The two methods named display are:
  - `Question display`
    - Displays the instance variable text `String`
  - `ChoiceQuestion display`
    - Overrides `Question display` method
    - Displays the instance variable text `String`
    - Displays the local list of choices

Calling Superclass Methods

- Consider the display method of the `ChoiceQuestion` class
  - It needs to display the question AND the list of choices
- `text` is a private instance variable of the superclass
  - How do you get access to it to print the question?
  - Call the `display` method of the superclass `Question`!
    - From a subclass, preface the method name with:
    - `super`

```
In which country was the inventor of Java born?
1. Australia
2. Canada
3. Denmark
4. United States
```

```
public void display()
{
   // Display the question text
   super.display(); // OK
   // Display the answer choices
   . . .
}
```

QuestionDemo2.java (1)

```
1  import java.util.Scanner;
2
3  /**
4     This program shows a simple quiz with two choice questions.
5  */
6  public class QuestionDemo2
7  {
8     public static void main(String[] args)
9     {
10       ChoiceQuestion first = new ChoiceQuestion();
11       first.setText("What was the original name of the Java language?");
12       first.addChoice("*7", false);
13       first.addChoice("Duke", false);
14       first.addChoice("Oak", true);
15       first.addChoice("Gosling", false);
16
17       ChoiceQuestion second = new ChoiceQuestion();
18       second.setText("In which country was the inventor of Java born?");
19       second.addChoice("Australia", false);
20       second.addChoice("Canada", true);
21       second.addChoice("Denmark", false);
22       second.addChoice("United States", false);
23
24       presentQuestion(first);
25       presentQuestion(second);
26    }
```

Creates two objects of the `ChoiceQuestion` class, uses new `addChoice` method.

Calls `presentQuestion` (next page)

QuestionDemo2.java (2)

```
28    /**
29       Presents a question to the user and checks the response.
30       @param q the question
31    */
32    public static void presentQuestion(ChoiceQuestion q)
33    {
34       q.display();
35       System.out.print("Your answer: ");
36       Scanner in = new Scanner(System.in);
37       String response = in.nextLine();
38       System.out.println(q.checkAnswer(response));
39    }
40 }
```

Uses `ChoiceQuestion` (subclass) display method.

ChoiceQuestion.java (1)

```
1  import java.util.ArrayList;
2
3  /**
4     A question with multiple choices.
5  */
6  public class ChoiceQuestion extends Question
7  {
8     private Array
9
10    /**
11       Construct
12    */
13    public Choic
14    {
15       choices =
16    }
```

Inherits from `Question` class.

```
17
18    /**
19       Adds an answer choice to this question.
20       @param choice the choice to add
21       @param correct true if this is the correct choice, false otherwise
22    */
23    public void addChoice(String choice, boolean correct)
24    {
25       choices.add(choice);
26       if (correct)
27       {
28          // Convert choices.size() to string
29          String choiceString = "" + choices.size();
30          setAnswer(choiceString);
31       }
32    }
```

New `addChoice` method.

ChoiceQuestion.java (2)

```
33
34    public void display()
35    {
36       // Display the question text
37       super.display();
38       // Display the answer choices
39       for (int i = 0; i < choices.size(); i++)
40       {
41          int choiceNumber = i + 1;
42          System.out.println(choiceNumber + ": " + choices.get(i));
43       }
44    }
45 }
```

Overridden `display` method.

Program Run

```
Who was the inventor of Java?
Your answer: Bjarne Stroustrup
false
In which country was the inventor of Java born?
1: Australia
2: Canada
3: Denmark
4: United States
Your answer: 2
true
```

Self Check 9.11

What is wrong with the following implementation of the display method?

```
public class ChoiceQuestion
{
   . . .
   public void display()
   {
      System.out.println(text);
      for (int i = 0; i < choices.size(); i++)
      {
         int choiceNumber = i + 1;
         System.out.println(choiceNumber + ": " +
choices.get(i));
      }
   }
}
```

Answer: The method is not allowed to access the instance variable `text` from the superclass.

Self Check 9.12

What is wrong with the following implementation of the display method?

```
public class ChoiceQuestion
{
   . . .
   public void display()
   {
      this.display();
      for (int i = 0; i < choices.size(); i++)
      {
         int choiceNumber = i + 1;
         System.out.println(choiceNumber + ": " +
choices.get(i));
      }
   }
}
```

Answer: The type of the `this` reference is `ChoiceQuestion`. Therefore, the `display` method of `ChoiceQuestion` is selected, and the method calls itself.

Self Check 9.13

Look again at the implementation of the `addChoice` method that calls the `setAnswer` method of the superclass. Why don't you need to call `super.setAnswer`?

Answer: Because there is no ambiguity. The subclass doesn't have a `setAnswer` method.

Self Check 9.14

In the `Manager` class of Self Check 7, override the `getName` method so that managers have a `*` before their name (such as `*Lin, Sally`).

Answer:

```
public String getName()
{
   return "*" + super.getName();
}
```

Self Check 9.15

In the `Manager` class of Self Check 9, override the `getSalary` method so that it returns the sum of the salary and the bonus.

Answer:

```
public double getSalary()
{
   return super.getSalary() + bonus;
}
```

Common Error

- Accidental Overloading

```
println(int x);
println(String s);  // Overloaded
```

  - Remember that **overloading** is when two methods share the same name but have different parameters
  - **Overriding** is where a subclass defines a method with the same name and exactly the same parameters as the superclass method
    - `Question display()` method
    - `ChoiceQuestion display()` method
  - If you intend to **override**, but change parameters, you will be **overloading** the inherited method, not **overriding** it
    - `ChoiceQuestion display(printStream out)` method

Common Error

- Forgetting to use `super` when invoking a Superclass method
  - Assume that `Manager` inherits from `Employee`
    - `getSalary` is an overridden method of `Employee`
      - `Manager.getSalary` includes an additional bonus

```
public class Manager extends Employee
{
   . . .
   public double getSalary()
   {
     double baseSalary = getSalary();    // Manager.getSalary
     //  should be super.getSalary();    // Employee.getSalary
     return baseSalary + bonus;
   }
}
```

Special Topic

- Calling the Superclass Constructor
  - When a subclass is instantiated, it will call the superclass constructor with no arguments
  - If you prefer to call a more specific constructor, you can invoke it by using replacing the superclass name with the reserved word `super` followed by `()`:

```
public ChoiceQuestion(String questionText)
{
   super(questionText);
   choices = new ArrayList<String>();
}
```

  - It must be the first statement in your constructor

Syntax 9.2 Constructor with Superclass Initializer

- To initialize private instance variables in the superclass, invoke a specific constructor

Syntax

```
public ClassName(parameterType parameterName, . . .)
{
   super(arguments);
   . . .
}
```

```
public ChoiceQuestion(String questionText)
{
   super(questionText);
   choices = new ArrayList<String>;
}
```

The superclass constructor is called first.

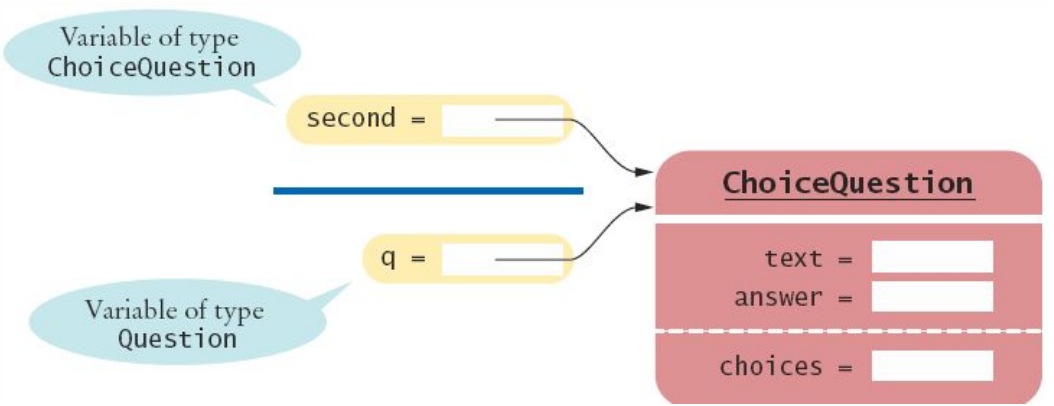
The constructor body can contain additional statements.

If you omit the superclass constructor call, the superclass constructor with no arguments is invoked.

Polymorphism

- `QuestionDemo2` passed two `ChoiceQuestion` objects to the `presentQuestion` method
  - Can we write a `presentQuestion` method that displays both `Question` and `ChoiceQuestion` types?
  - **How would that work?**

```
public static void presentQuestion(Question q)
```



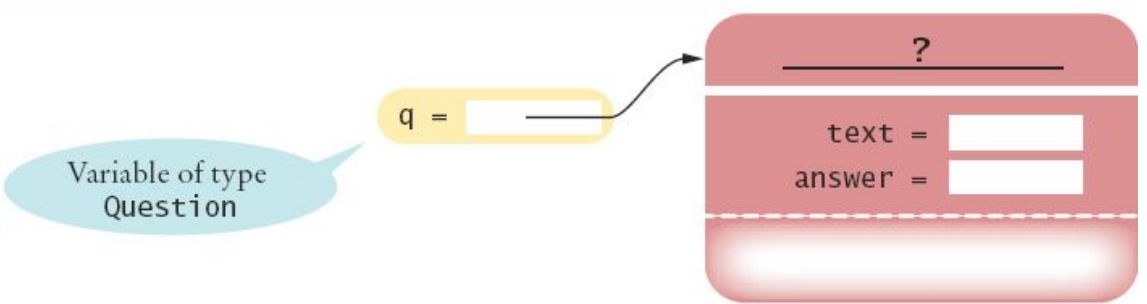
A subclass reference can be used when a superclass reference is expected.

Which `display` Method Was Called?

- `presentQuestion` simply calls the display method of whatever type is passed:

```
public static void presentQuestion(Question q)
{
   q.display();
   . . .
```

- If passed an object of the `Question` class:
  - `Question display`
- If passed an object of the `ChoiceQuestion` class:
  - `ChoiceQuestion display`
- The variable `q` does not know the type of object to which it refers:



Polymorphism Benefits

- In Java, method calls *are always determined by the type of the actual object,* **not** the type of the variable containing the object reference
  - This is called *dynamic method lookup*
  - Dynamic method lookup allows us to treat objects of different classes in a uniform way
- This feature is called **polymorphism**
- We ask multiple objects to carry out a task, and each object does so in its own way
- Polymorphism makes programs *easily extensible*

QuestionDemo3.java (1)

```
1  import java.util.Scanner;
2
3  /**
4     This program shows a simple quiz with two question types.
5  */
6  public class QuestionDemo3
7  {
8     public static void main(String[] args)
9     {
10       Question first = new Question();
11       first.setText("Who was the inventor of Java?");
12       first.setAnswer("James Gosling");
13
14       ChoiceQuestion second = new ChoiceQuestion();
15       second.setText("In which country was the inventor of Java born?");
16       second.addChoice("Australia", false);
17       second.addChoice("Canada", true);
18       second.addChoice("Denmark", false);
19       second.addChoice("United States", false);
20
21       presentQuestion(first);
22       presentQuestion(second);
23    }
24
```

Creates an object of the `Question` class

Creates an object of the `ChoiceQuestion` class, uses new `addChoice` method.

Calls `presentQuestion` (next page) passing both types of objects.

QuestionDemo3.java (2)

```
24
25    /**
26       Presents a question to the user and checks the response.
27       @param q the question
28    */
29    public static void presentQuestion(Question q)
30    {
31       q.display();
32       System.out.print("Your answer: ");
33       Scanner in = new Scanner(System.in);
34       String response = in.nextLine();
35       System.out.println(q.checkAnswer(response));
36    }
37 }
```

Receives a parameter of the super-class type

Uses appropriate `display` method.

Self Check 9.16

Assuming `SavingsAccount` is a subclass of `BankAccount`, which of the following code fragments are valid in Java?

a. `BankAccount account = new SavingsAccount();`

b. `SavingsAccount account2 = new BankAccount();`

c. `BankAccount account = null;`

d. `SavingsAccount account2 = account;`

Answer: a and c.

Self Check 9.17

If `account` is a variable of type `BankAccount` that holds a non-`null` reference, what do you know about the object to which `account` refers?

Answer: It belongs to the class `BankAccount` or one of its subclasses.

Self Check 9.18

Declare an array quiz that can hold a mixture of `Question` and `ChoiceQuestion` objects.

Answer: `Question[] quiz = new Question[SIZE];`

Self Check 9.19

Consider the code fragment

```
ChoiceQuestion cq = . . .; // A non-null value
cq.display();
```

Which actual method is being called?

Answer: You cannot tell from the fragment—`cq` may be initialized with an object of a subclass of `ChoiceQuestion`. The `display` method of whatever object `cq` references is invoked.

Self Check 9.20

Is the method call `Math.sqrt(2)` resolved through dynamic method lookup?

Answer: No. This is a static method of the `Math` class. There is no implicit parameter object that could be used to dynamically look up a method.

Special Topic

- Dynamic Method Lookup and the Implicit Parameter
  - Suppose we move the `presentQuestion` method to inside the `Question` class and call it as follows:

```
ChoiceQuestion cq = new ChoiceQuestion();
cq.setText("In which country was the inventor of Java born?");
. . .
cq.presentQuestion();
```

```
void presentQuestion()
{
  display();
  System.out.print("Your answer: ");
  Scanner in = new Scanner(System.in);
  String response = in.nextLine();
  System.out.println(checkAnswer(response));
}
```

  - Which `display` and `checkAnswer` methods will be called?

Dynamic Method Lookup

- Add the Implicit Parameter to the code to find out
  - Because of dynamic method lookup, the `ChoiceQuestion` versions of the `display` and `checkAnswer` methods are called automatically.
  - This happens even though the `presentQuestion` method is declared in the `Question` class, which has no knowledge of the `ChoiceQuestion` class.

```
public class Question
{
   void presentQuestion()
   {
      this.display();
      System.out.print("Your answer: ");
      Scanner in = new Scanner(System.in);
      String response = in.nextLine();
      System.out.println(this.checkAnswer(response));
   }
```

Special Topic

- Abstract Classes
  - If it is desirable to ***force*** subclasses to override a method of a base class, you can declare a method as `abstract`.
  - You cannot instantiate an object that has `abstract` methods
    - Therefore the class is considered `abstract`

```
public abstract class Account
{
  public abstract void deductFees();  // no method implementation
. . .
```

```
public class SavingsAccount extends Account // Not abstract
{
  public void deductFees() // Provides an implementation
  {   // method implementation. . .  }
  . . .
}
```

  - If you extend the `abstract` class, you must implement all `abstract` methods.

Abstract References

- A class that can be instantiated is called `concrete` class
- You cannot instantiate an object that has `abstract` methods
  - But you can declare an object reference whose type is an `abstract` class
  - The actual object to which it refers must be an instance of a `concrete` subclass

```
Account anAccount;          // OK: Reference to abstract object
anAccount = new Account(); // Error: Account is abstract
anAccount = new SavingsAccount(); // Concrete class is OK
anAccount = null;          // OK
```

  - This allows for polymorphism based on even an `abstract` class!

One reason for using `abstract` classes is to force programmers to create subclasses.

Special Topic

- Final Methods and Classes
  - You can also ***prevent*** programmers from creating subclasses and override methods using `final`.
  - The `String` class in the Java library is an example:

```
public final class String { . . . }
```

  - Example of a method that cannot be overridden:

```
public class SecureAccount extends BankAccount
{
   . . .
   public final boolean checkPassword(String password)
   {
      . . .
   }
}
```

Special Topic

- `protected` Access
  - When trying to implement the `display` method of the `ChoiceQuestion` class, the `display` method wanted to access the instance variable `text` of the superclass, but it was `private`.
  - We chose to use a method of the superclass to display the text.
- Java provides a more elegant solution
  - The superclass can declare an instance variable as `protected` instead of `private`
  - `protected` data in an object can be accessed by the methods of the object's class and all its subclasses
  - But it can also be accessed by all other classes in the same package!

```
public class Question
{
   protected String text;
   . . .
}
```

If you want to grant access to the data to subclass methods only, consider making the accessor method protected.

Steps to Using Inheritance

- As an example, we will consider a bank that offers customers the following account types:
  - 1) A savings account that earns interest. The interest compounds monthly and is based on the minimum monthly balance.
  - 2) A checking account that has no interest, gives you three free withdrawals per month, and charges a $1 transaction fee for each additional withdrawal.
- The program will manage a set of accounts of both types
  - It should be structured so that other account types can be added without affecting the main processing loop.
- The menu: `D)eposit W)ithdraw M)onth end Q)uit`
  - For deposits and withdrawals, query the account number and amount. Print the balance of the account after each transaction.
  - In the “Month end” command, accumulate interest or clear the transaction counter, depending on the type of the bank account. Then print the balance of all accounts.

Steps to Using Inheritance

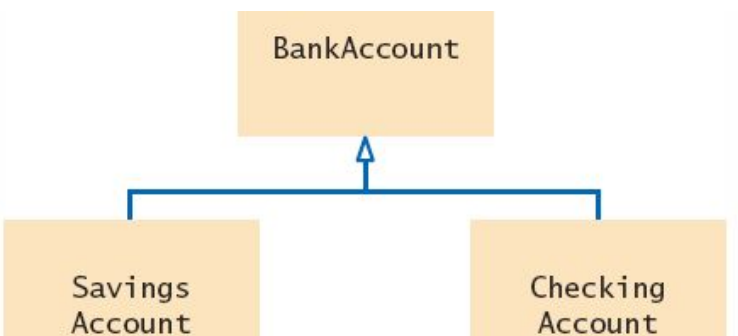
1) List the classes that are part of the hierarchy.

`SavingsAccount`

`CheckingAccount`

2) Organize the classes into an inheritance.
   hierarchy
   Base on superclass `BankAccount`

3) Determine the common responsibilities.
   a. Write Pseudocode for each task
   b. Find common tasks



Using Inheritance

```
For each user command
    If it is a deposit or withdrawal
        Deposit or withdraw the amount from the specified account.
        Print the balance.
    If it is month end processing
        For each account
            Call month end processing.
            Print the balance.
```

```
Deposit money.
Withdraw money.
Get the balance.
Carry out month end processing.
```

Steps to Using Inheritance

4) Decide which methods are overridden in subclasses.

   For each subclass and each of the common responsibilities, decide whether the behavior can be inherited or whether it needs to be overridden.

5) Declare the public interface of each subclass.

   Typically, subclasses have responsibilities other than those of the superclass. List those, as well as the methods that need to be overridden.

   You also need to specify how the objects of the subclasses should be constructed.

6) Identify instance variables.

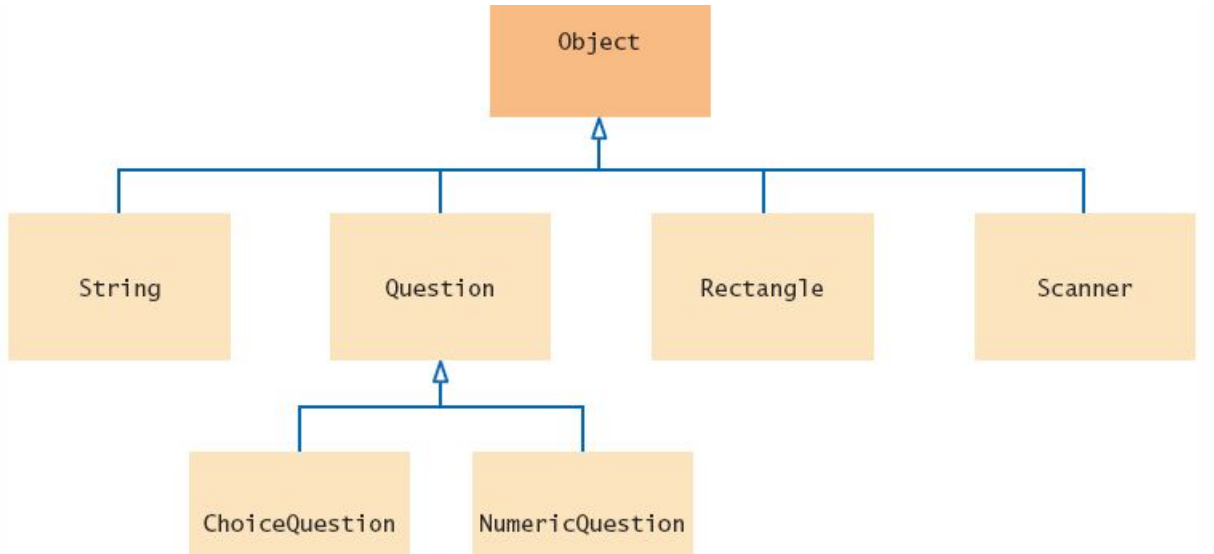
   List the instance variables for each class. Place instance variables that are common to all classes in the base of the hierarchy.

7) Implement constructors and methods.

8) Construct objects of different subclasses and process them.

`Object`: The Cosmic Superclass

- In Java, every class that is declared without an explicit extends clause automatically extends the class `Object`



The methods of the `Object` class are very general. You will learn to override the `toString` method.

Writing a `toString` Method

- The `toString` method returns a `String` representation for each object
- The `Rectangle` class (`java.awt`) has a `toString` method
  - You can invoke the `toString` method directly

```
Rectangle box = new Rectangle(5, 10, 20, 30);
String s = box.toString();          // Call toString directly
// Sets s to "java.awt.Rectangle[x=5,y=10,width=20,height=30]"
```

  - The `toString` method can also be invoked implicitly whenever you concatenate a `String` with an object:

```
System.out.println("box=" + box);   // Call toString implicitly
```

- The compiler can invoke the `toString` method, because it knows that *every object* has a `toString` method:
  - Every class extends the `Object` class, and can override `toString`

Overriding the `toString` Method

- Example: Override the `toString` method for the `BankAccount` class

```
BankAccount momsSavings = new BankAccount(5000);
String s = momsSavings.toString();
// Sets s to something like "BankAccount@d24606bf"
```

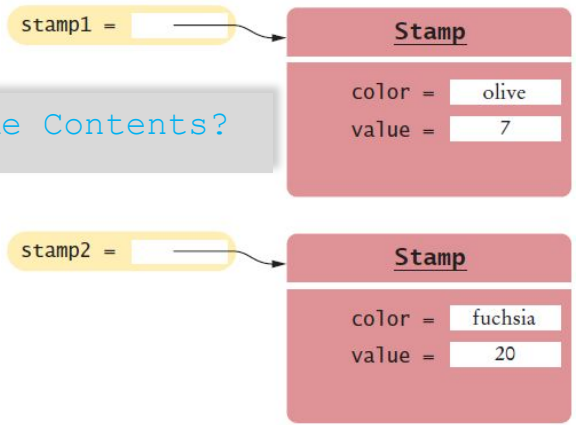
  - All that is printed is the name of the class, followed by the hash code which can be used to tell objects (Chapter 10)
- We want to know what is inside the object

```
public class BankAccount
{
   public String toString()
   {
      // returns "BankAccount[balance=5000]"
      return "BankAccount[balance=" + balance + "]";
   }
}
```

Override the `toString` method to yield a string that describes the object's state.

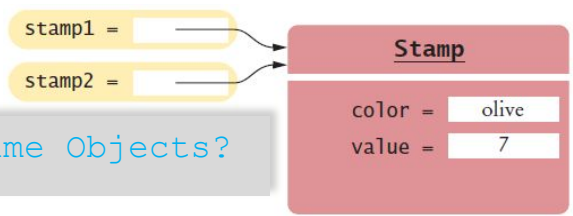
Overriding the `equals` Method

- In addition to the `toString` method, the Object class `equals` method checks whether two objects have the same contents:




```
if (stamp1.equals(stamp2)) . . .// same Contents?
```

- This is different from the == operator which compares the two references:




```
if (stamp1 == stamp2) . . .// same Objects?
```

Overriding the `equals` Method

- The Object class specifies the type of parameter as `Object`

```
public class Stamp
{
   private String color;
   private int value;
   . . .
   public boolean equals(Object otherObject)
   {
     . . .
   }
   . . .
}
```

The `Stamp equals` method must declare the same type of parameter as the `Object equals` method to override it.

```
public boolean equals(Object otherObject)
{
   Stamp other = (Stamp) otherObject;
   return color.equals(other.color)
     && value == other.value;
}
```

Cast the parameter variable to the class `Stamp`

The `instanceof` Operator

- It is legal to store a subclass reference in a variable declared as superclass reference type
- The opposite conversion is also possible:
  - From a superclass reference to a subclass reference
  - If you have a variable of type `Object`, and you know that it actually holds a `Question` reference, you can cast it:

```
Question q = (Question) obj;
```

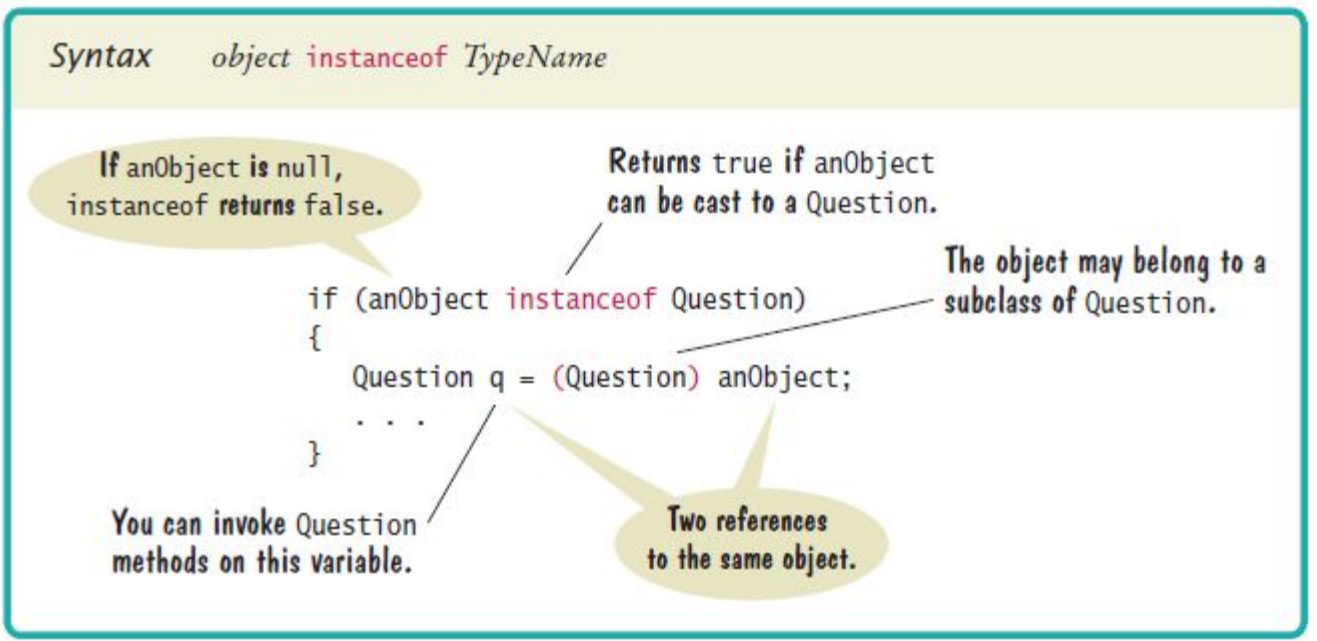
- To make sure it is an object of the `Question` type, you can test it with the `instanceof` operator:

```
if (obj instanceof Question)
{
  Question q = (Question) obj;
}
```

`instanceof` returns a boolean

Syntax 9.3 Using `instanceof`

- Using the `instanceof` operator also involves casting
  - Returns true if you can safely cast one object to another
- Casting allows the use of methods of the new object
  - Most often used to make a reference more specific
    - Cast from an `Object` reference to a more specific class type



Self Check 9.21

Why does the call

```
System.out.println(System.out);
```

produce a result such as `java.io.PrintStream@7a84e4` ?

Answer: Because the implementor of the `PrintStream` class did not supply a `toString` method.

Self Check 9.22

Will the following code fragment compile? Will it run? If not, what error is reported?

```
Object obj = "Hello";
System.out.println(obj.length());
```

Answer: The second line will not compile. The class `Object` does not have a method `length`.

Self Check 9.23

Will the following code fragment compile? Will it run? If not, what error is reported?

```
Object obj = "Who was the inventor of Java?";
Question q = (Question) obj;
q.display();
```

Answer: The code will compile, but the second line will throw a class cast exception because `Question` is not a subclass of `String`.

Self Check 9.24

Why don't we simply store all objects in variables of type `Object`?

Answer: There are only a few methods that can be invoked on variables of type `Object`.

Self Check 9.25

Assuming that `x` is an object reference, what is the value of `x instanceof Object` ?

Answer: The value is `false` if `x` is `null` and `true` otherwise.

Common Error

- Don't Use Type Tests

```
if (q instanceof ChoiceQuestion)) // Don't do this
{
  // Do the task the ChoiceQuestion way
}
else if (q instanceof Question))
{
  // Do the task the Question way
}
```

- This is a poor strategy. If a new class is added, then all these queries need to be revised.
  - When you add the class `NumericQuestion`
- Let polymorphism select the correct method:
  - Declare a method `doTheTask` in the superclass
  - Override it in subclasses

Special Topic

- Inheritance and the `toString` Method
  - Instead of writing the type of object in a `toString` method
    - Use `getclass` (inherited from object) in the superclass

```
public class BankAccount { . . .
  public String toString()
  {
    return getClass().getName() + "[balance=" + balance + "]";
  }
```

  - Then use inheritance, call the superclass `toString` first

```
public class SavingsAccount extends BankAccount
{
  . . .
  public String toString()
  {
    return super.toString() + "[interestRate=" + intRate + "]";
  }  // returns SavingsAccount[balance= 10000][interestRate= 5]
}
```

This allows the superclass to output private instance variables

Special Topic

- Inheritance and the `equals` Method
  - What if someone called `stamp1.equals(x)` where `x` was not a `Stamp` object?
    - Using the `instanceof` operator, it would be possible for `otherObject` to belong to some subclass of `Stamp`
  - Use the `getClass` method to compare your exact class to the passed object to make sure

Insures comparison of the same types

```
public boolean equals(Object otherObject)
{
  if (otherObject == null) { return false; }
  if (getClass() != otherObject.getClass()) { return false; }
  Stamp other = (Stamp) otherObject;
  return color.equals(other.color) && value == other.value;
}
```

Interface Types

- An `interface` is a special type of declaration that lists a set of methods and their signatures
  - A class that '*implements*' the `interface` must implement all of the methods of the `interface`
  - It is similar to a class, but there are differences:
    - All methods in an interface type are abstract:
      - They have a name, parameters, and a return type, but they don't have an implementation
    - All methods in an interface type are automatically public
    - An interface type cannot have instance variables
    - An interface type cannot have static methods

```
public interface Measurable
{
   double getMeasure();
}
```

A Java `interface` type declares a set of methods and their signatures.

Syntax 9.4 Interface Types

- An `interface` declaration and a class that `implements` the `interface`.

Syntax

Declaring:

```
public interface InterfaceName
{
   method declarations
}
```

Implementing:

```
public class ClassName implements InterfaceName, InterfaceName, . . .
{
   instance variables
   methods
}
```

```
public interface Measurable
{
   double getMeasure();
}

public class BankAccount implements Measurable
{
   . . .

   public double getMeasure()
   {
      return balance;
   }
}
```

Interface methods are automatically public.

Abstract methods have no implementation.

A class can implement one or more interface types.

Other BankAccount methods.

Implementation for the abstract method that was declared in the interface type.

Using Interface Types

- We can use the interface type `Measurable` to implement a "universal" static method for computing averages:

```
public interface Measurable
{
  double getMeasure();
}
```

```
public static double average(Measurable[] objs)
{
  if (objs.length == 0) return 0;
  double sum = 0;
  for (Measurable obj : objs)
  {
    sum = sum + obj.getMeasure();
  }
  return sum / objs.length;
}
```

Implementing an Interface

- A class can be declared to `implement` an interface
  - The class must implement all methods of the interface

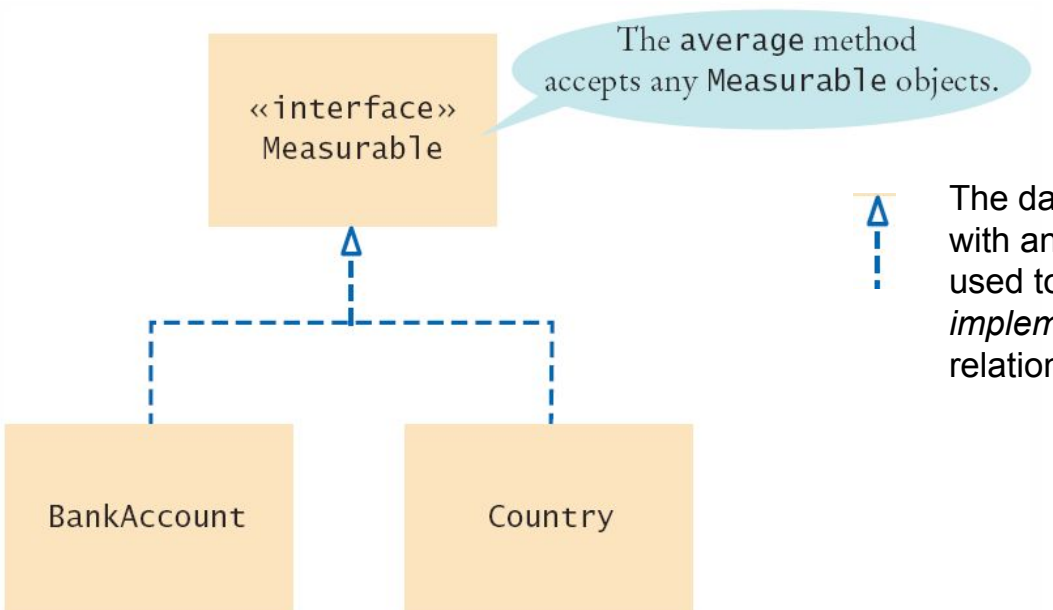
```
public class BankAccount implements Measurable
{
   public double getMeasure()
   {
      return balance;
   }
   . . .
}
```

Use the `implements` reserved word in the class declaration.

```
public class Country implements Measurable
{
   public double getMeasure()
   {
      return area;
   }
   . . .
}
```

The methods of the interface must be declared as `public`

An Implementation Diagram



The dashed line with an arrow is used to denote *implements* relationships

MeasureableDemo.java (1)

```
1  /**
2     This program demonstrates the measurable BankAccount and Country classes.
3  */
4  public class MeasurableDemo
5  {
6     public static void main(String[] args)
7     {
8        Measurable[] accounts = new Measurable[3];
9        accounts[0] = new BankAccount(0);
10       accounts[1] = new BankAccount(10000);
11       accounts[2] = new BankAccount(2000);
12
13       System.out.println("Average balance: "
14          + average(accounts));
15
16       Measurable[] countries = new Measurable[3];
17       countries[0] = new Country("Uruguay", 176220);
18       countries[1] = new Country("Thailand", 514000);
19       countries[2] = new Country("Belgium", 30510);
20
21       System.out.println("Average area: "
22          + average(countries));
23    }
```

MeasureableDemo.java (2)

```
25    /**
26       Computes the average of the measures of the given objects.
27       @param objs an array of Measurable objects
28       @return the average of the measures
29    */
30    public static double average(Measurable[] objs)
31    {
32       if (objs.length == 0) { return 0; }
33       double sum = 0;
34       for (Measurable obj : objs)
35       {
36          sum = sum + obj.getMeasure();
37       }
38       return sum / objs.length;
39    }
40 }
```

Program Run

```
Average balance: 4000.0
Average area: 240243.33333333334
```

The `Comparable` Interface

- The Java library includes a number of important interfaces including Comparable
  - It requires implementing one method: `compareTo()`
  - It is used to compare two objects
  - It is implemented by many objects in the Java API
  - You may want to implement it in your classes to use powerful Java API tools such as sorting
- It is called on one object, and is passed another
  - Called on object a, is passed b, and return values include:
    - Negative: a comes before b
    - Positive: a comes after b
    - 0: a is the same as b

```
a.compareTo(b);
```

Implementing an Interface

- Defining the `compareTo` method ensures that `BankAccount` implements the `Comparable` interface

```
public class BankAccount implements Comparable
{
   . . .
   public int compareTo(Object otherObject)
   {
      BankAccount other = (BankAccount) otherObject;
      if (balance < other.balance) { return 1; }
      if (balance > other.balance) { return 1; }
      return 0;
   }
   . . .
}
```

Using compareTo to Sort

- The `Arrays.sort` method uses the `compareTo` method to sort the elements of the array
  - Once the `BankAccount` class implements the `Comparable` interface, you can sort an array of bank accounts with the `Arrays.sort` method:

```
BankAccount[] accounts = new BankAccount[3];
accounts[0] = new BankAccount(10000);
accounts[1] = new BankAccount(0);
accounts[2] = new BankAccount(2000);
Arrays.sort(accounts);
```

  - The array is now sorted by increasing balance

Implementing Java Library interfaces allows you to use the power of the Java Library with your classes.

Self Check 9.26

Suppose you want to use the `average` method to find the average salary of `Employee` objects. What condition must the `Employee` class fulfill?

Answer: It must implement the `Measurable` interface and provide a `getMeasure` method returning the salary.

Self Check 9.27

Why can't the `average` method have a parameter variable of type `Object[]`?

Answer: The `Object` class doesn't have a `getMeasure` method.

Self Check 9.28

Why can't you use the `average` method to find the average length of `String` objects?

Answer: You cannot modify the `String` class to implement `Measurable`—it is a library class. See Special Topic 9.10 for a solution.

Self Check 9.29

What is wrong with this code?

```
Measurable meas = new Measurable();
System.out.println(meas.getMeasure());
```

Answer: `Measurable` is not a class. You cannot construct objects of type `Measurable`.

Self Check 9.30

How can you sort an array of `Country` objects by increasing area?

Answer: Have the `Country` class implement the `Comparable` interface, as shown below, and call `Arrays.sort`.

```
public class Country implements Comparable
{
   . . .
   public int compareTo(Object otherObject)
   {
      Country other = (Country) otherObject;
      if (area < other.area) return -1;
      if (area > other.area) return 1;
      return 0;
   }
}
```

Self Check 9.31

Can you use the `Arrays.sort` method to sort an array of `String` objects? Check the API documentation for the `String` class.

Answer: Yes, you can, because `String` implements the `Comparable` interface type.

Common Error

- Forgetting to Declare Implementing Methods as Public
  - The methods in an interface are not declared as public, because they are public by default.
  - However, the methods in a class are not public by default.
  - It is a common error to forget the public reserved word when declaring a method from an interface:

```
public class BankAccount implements Measurable
{
   double getMeasure()   // Oops—should be public
   {
      return balance;
   }
   . . .
}
```

Special Topic

- Interface Constants
  - Interfaces cannot have instance variables, but it is legal to specify constants
  - When declaring a constant in an interface, you can (and should) omit the reserved words `public static final`, because all variables in an interface are automatically `public static final`

```
public interface SwingConstants
{
   int NORTH = 1;
   int NORTHEAST = 2;
   int EAST = 3;
   . . .
}
```

Special Topic

- Generic Interface Types
  - The type parameter specifies the type of the objects that this class is willing to accept for comparison.
- The `Comparable` interface uses a special type of parameter that allows it to work with any type:

```
public interface Comparable<T>
{
   int compareTo(T other);
}
```

  - The type `<T>` is a placeholder for an actual type of object

```
ArrayList<String> names = new ArrayList<String>();
```

- The `BankAccount` class can be reworked using the generic version of the `Comparable` interface

```
public class BankAccount implements Comparable<BankAccount>
{
   . . .
   public int compareTo(BankAccount other)
   {
      return Double.compare(balance, other.balance);
   }
   . . .
}
```

No need to cast to convert an `Object` parameter variable into the desired type.

Special Topic (1)

- Function Objects
  - Interfaces work well IF all objects that need the service are willing to implement the interface.
  - The sole purpose of a function object is to execute a single method
    - This allows a non-implementing class to use the services of the interface by creating a function object and using it's method
  - First, create a new interface
    - The measure method measures an object and returns its measurement. We use a parameter of type `Object`, the "lowest common denominator" of all classes in Java, because we do not want to restrict which classes can be measured.

```
public interface Measurer
{
   double measure(Object anObject);
}
```

Special Topic (2)

- Then declare a class that implements the new interface

```
public class StringMeasurer implements Measurer
{
  public double measure(Object obj)
  {
    String str = (String) obj; // Cast obj to String type
    return str.length();
  }
}
```

```
public interface Measurer
{
  double measure(Object anObject);
}
```

Special Topic (3)

- Example of Function Object Use
  - Instantiate an object of the Function object class
  - Call your method that accepts an object of this type

```
String[] words = { "Mary", "had", "a", "little", "lamb" };
Measurer strMeas = new StringMeasurer();
double result = average(words, strMeas);
```

```
public static double average(Object[] objs, Measurer meas)
{
  if (objs.length == 0) { return 0; }
  double sum = 0;
  for (Object obj : objs)
  {
    sum = sum + meas.measure(obj);
  }
  return sum / objs.length;
}
```