2

Object Orientation

CERTIFICATION OBJECTIVES

- Declare Interfaces
- Declare, Initialize, and Use Class Members
- Use Overloading and Overriding
- Develop Constructors
- Describe Encapsulation, Coupling, and Cohesion
- Use Polymorphism
- Relate Modifiers and Inheritance
- Use Superclass Constructors and Overloaded Constructors
- Use IS-A and HAS-A Relationships

✓ Two-Minute Drill

Q&A Self Test

Being an SCJP 6 means you must be at one with the object-oriented aspects of Java. You must dream of inheritance hierarchies, the power of polymorphism must flow through you, cohesion and loose coupling must become second nature to you, and composition must be your bread and butter. This chapter will prepare you for all of the object-oriented objectives and questions you'll encounter on the exam. We have heard of many experienced Java programmers who haven't really become fluent with the object-oriented tools that Java provides, so we'll start at the beginning.

CERTIFICATION OBJECTIVE

Encapsulation (Exam Objective 5.1)

5.1 Develop code that implements tight encapsulation, loose coupling, and high cohesion in classes, and describe the benefits.

Imagine you wrote the code for a class, and another dozen programmers from your company all wrote programs that used your class. Now imagine that later on, you didn't like the way the class behaved, because some of its instance variables were being set (by the other programmers from within their code) to values you hadn't anticipated. *Their* code brought out errors in *your* code. (Relax, this is just hypothetical.) Well, it is a Java program, so you should be able just to ship out a newer version of the class, which they could replace in their programs without changing any of their own code.

This scenario highlights two of the promises/benefits of Object Orientation (OO): flexibility and maintainability. But those benefits don't come automatically. You have to do something. You have to write your classes and code in a way that supports flexibility and maintainability. So what if Java supports OO? It can't design your code for you. For example, imagine if you made your class with `public` instance variables, and those other programmers were setting the instance variables directly, as the following code demonstrates:

```
public class BadOO {
   public int size;
```

```
    public int weight;
    ...
}
public class ExploitBadOO {
    public static void main (String [] args) {
        BadOO b = new BadOO();
        b.size = -5; // Legal but bad!!
    }
}
```

And now you're in trouble. How are you going to change the class in a way that lets you handle the issues that come up when somebody changes the `size` variable to a value that causes problems? Your only choice is to go back in and write method code for adjusting `size` (a `setSize(int a)` method, for example), and then protect the `size` variable with, say, a private access modifier. But as soon as you make that change to your code, you break everyone else's!

The ability to make changes in your implementation code without breaking the code of others who use your code is a key benefit of encapsulation. You want to hide implementation details behind a public programming interface. By interface, we mean the set of accessible methods your code makes available for other code to call—in other words, your code's API. By hiding implementation details, you can rework your method code (perhaps also altering the way variables are used by your class) without forcing a change in the code that calls your changed method.

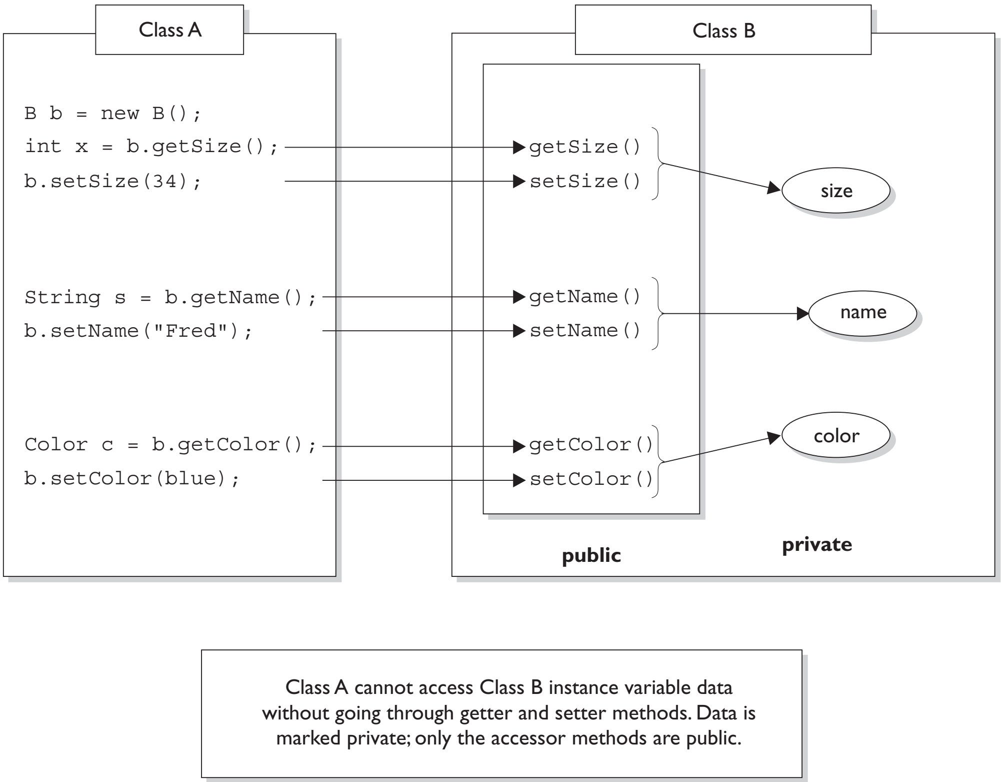
If you want maintainability, flexibility, and extensibility (and of course, you do), your design must include encapsulation. How do you do that?

- Keep instance variables protected (with an access modifier, often `private`).
- Make `public` accessor methods, and force calling code to use those methods rather than directly accessing the instance variable.
- For the methods, use the JavaBeans naming convention of `set<someProperty>` and `get<someProperty>`.

Figure 2-1 illustrates the idea that encapsulation forces callers of our code to go through methods rather than accessing variables directly.

FIGURE 2-1

The nature of encapsulation



We call the access methods getters and setters although some prefer the fancier terms accessors and mutators. (Personally, we don't like the word "mutate".) Regardless of what you call them, they're methods that other programmers must go through in order to access your instance variables. They look simple, and you've probably been using them forever:

```
public class Box {
   // protect the instance variable; only an instance
   // of Box can access it
   private int size;
   // Provide public getters and setters
   public int getSize() {
      return size;
```

```
    }
    public void setSize(int newSize) {
       size = newSize;
    }
 }
```

Wait a minute...how useful is the previous code? It doesn't even do any validation or processing. What benefit can there be from having getters and setters that add no additional functionality? The point is, you can change your mind later, and add more code to your methods without breaking your API. Even if today you don't think you really need validation or processing of the data, good OO design dictates that you plan for the future. To be safe, force calling code to go through your methods rather than going directly to instance variables. *Always*. Then you're free to rework your method implementations later, without risking the wrath of those dozen programmers who know where you live.

exam watch

Look out for code that appears to be asking about the behavior of a method, when the problem is actually a lack of encapsulation. Look at the following example, and see if you can figure out what's going on:

```
class Foo {
   public int left = 9;
   public int right = 3;
   public void setLeft(int leftNum) {
      left = leftNum;
      right = leftNum/3;
   }
   // lots of complex test code here
}
```

Now consider this question: Is the value of right always going to be one-third the value of left? It looks like it will, until you realize that users of the `Foo` ***class don't need to use the*** `setLeft()` ***method! They can simply go straight to the instance variables and change them to any arbitrary*** `int` ***value.***

CERTIFICATION OBJECTIVE

Inheritance, Is-A, Has-A (Exam Objective 5.5)

5.5 *Develop code that implements "is-a" and/or "has-a" relationships.*

Inheritance is everywhere in Java. It's safe to say that it's almost (almost?) impossible to write even the tiniest Java program without using inheritance. In order to explore this topic we're going to use the `instanceof` operator, which we'll discuss in more detail in Chapter 4. For now, just remember that `instanceof` returns `true` if the reference variable being tested is of the type being compared to. This code:

```
class Test {
  public static void main(String [] args) {
    Test t1 = new Test();
    Test t2 = new Test();
    if (!t1.equals(t2))
      System.out.println("they're not equal");
    if (t1 instanceof Object)
      System.out.println("t1's an Object");
  }
}
```

Produces the output:

```
they're not equal
t1's an Object
```

Where did that `equals` method come from? The reference variable `t1` is of type Test, and there's no `equals` method in the Test class. Or is there? The second `if` test asks whether `t1` is an instance of class Object, and because it *is* (more on that soon), the `if` test succeeds.

Hold on…how can `t1` be an instance of type Object, we just said it was of type Test? I'm sure you're way ahead of us here, but it turns out that every class in Java is a subclass of class Object, (except of course class Object itself). In other words, every class you'll ever use or ever write will inherit from class Object. You'll always have an `equals` method, a `clone` method, `notify`, `wait`, and others, available to use. Whenever you create a class, you automatically inherit all of class Object's methods.

Why? Let's look at that `equals` method for instance. Java's creators correctly assumed that it would be very common for Java programmers to want to compare instances of their classes to check for equality. If class Object didn't have an `equals` method, you'd have to write one yourself; you and every other Java programmer. That one `equals` method has been inherited billions of times. (To be fair, `equals` has also been *overridden* billions of times, but we're getting ahead of ourselves.)

For the exam you'll need to know that you can create inheritance relationships in Java by *extending* a class. It's also important to understand that the two most common reasons to use inheritance are

- To promote code reuse
- To use polymorphism

Let's start with reuse. A common design approach is to create a fairly generic version of a class with the intention of creating more specialized subclasses that inherit from it. For example:

```
class GameShape {
   public void displayShape() {
     System.out.println("displaying shape");
   }
   // more code
}

class PlayerPiece extends GameShape {
   public void movePiece() {
     System.out.println("moving game piece");
   }
   // more code
}


public class TestShapes {
   public static void main (String[] args) {
      PlayerPiece shape = new PlayerPiece();
      shape.displayShape();
      shape.movePiece();
   }
}
```

Outputs:

```
displaying shape
moving game piece
```

Notice that the `PlayingPiece` class inherits the generic `display()` method from the less-specialized class `GameShape`, and also adds its own method, `movePiece()`. Code reuse through inheritance means that methods with generic functionality (like `display()`)—that could apply to a wide range of different kinds of shapes in a game—don't have to be reimplemented. That means all specialized subclasses of `GameShape` are guaranteed to have the capabilities of the more generic superclass. You don't want to have to rewrite the `display()` code in each of your specialized components of an online game.

But you knew that. You've experienced the pain of duplicate code when you make a change in one place and have to track down all the other places where that same (or very similar) code exists.

The second (and related) use of inheritance is to allow your classes to be accessed polymorphically—a capability provided by interfaces as well, but we'll get to that in a minute. Let's say that you have a `GameLauncher` class that wants to loop through a list of different kinds of `GameShape` objects, and invoke `display()` on each of them. At the time you write this class, you don't know every possible kind of `GameShape` subclass that anyone else will ever write. And you sure don't want to have to redo *your* code just because somebody decided to build a Dice shape six months later.

The beautiful thing about polymorphism ("many forms") is that you can treat any *subclass* of `GameShape` as a `GameShape`. In other words, you can write code in your `GameLauncher` class that says, "I don't care what kind of object you are as long as you inherit from (extend) `GameShape`. And as far as I'm concerned, if you extend `GameShape` then you've definitely got a `display()` method, so I know I can call it."

Imagine we now have two specialized subclasses that extend the more generic `GameShape` class, `PlayerPiece` and `TilePiece`:

```
class GameShape {
   public void displayShape() {
     System.out.println("displaying shape");
   }
   // more code
}
```

```
class PlayerPiece extends GameShape {
   public void movePiece() {
     System.out.println("moving game piece");
   }
   // more code
}

class TilePiece extends GameShape {
    public void getAdjacent() {
      System.out.println("getting adjacent tiles");
    }
    // more code
}
```

Now imagine a test class has a method with a declared argument type of `GameShape`, that means it can take any kind of `GameShape`. In other words, any subclass of `GameShape` can be passed to a method with an argument of type `GameShape`. This code

```
public class TestShapes {
   public static void main (String[] args) {
      PlayerPiece player = new PlayerPiece();
      TilePiece tile = new TilePiece();
      doShapes(player);
      doShapes(tile);
   }

   public static void doShapes(GameShape shape) {
     shape.displayShape();
   }
}
```

Outputs:

```
displaying shape
displaying shape
```

The key point is that the `doShapes()` method is declared with a `GameShape` argument but can be passed any subtype (in this example, a subclass) of `GameShape`. The method can then invoke any method of `GameShape`, without any concern for the actual runtime class type of the object passed to the method. There are implications, though. The `doShapes()` method knows only that the objects are a type of `GameShape`, since that's how the parameter is declared. And using a reference variable declared as type `GameShape`—regardless of whether the variable is a method parameter, local variable, or instance variable—means that *only* the methods of `GameShape` can be invoked on it. The methods you can call on a reference are totally dependent on the *declared* type of the variable, no matter what the actual object is, that the reference is referring to. That means you can't use a `GameShape` variable to call, say, the `getAdjacent()` method even if the object passed in *is* of type `TilePiece`. (We'll see this again when we look at interfaces.)

IS-A and HAS-A Relationships

For the exam you need to be able to look at code and determine whether the code demonstrates an IS-A or HAS-A relationship. The rules are simple, so this should be one of the few areas where answering the questions correctly is almost a no-brainer.

IS-A

In OO, the concept of IS-A is based on class inheritance or interface implementation. IS-A is a way of saying, "this thing is a type of that thing." For example, a Mustang is a type of horse, so in OO terms we can say, "Mustang IS-A Horse." Subaru IS-A Car. Broccoli IS-A Vegetable (not a very fun one, but it still counts). You express the IS-A relationship in Java through the keywords `extends` (for *class* inheritance) and `implements` (for *interface* implementation).

```
public class Car {
  // Cool Car code goes here
}

public class Subaru extends Car {
   // Important Subaru-specific stuff goes here
   // Don't forget Subaru inherits accessible Car members which
   // can include both methods and variables.
}
```

A Car is a type of Vehicle, so the inheritance tree might start from the Vehicle class as follows:

```
public class Vehicle { ... }
public class Car extends Vehicle { ... }
public class Subaru extends Car { ... }
```

In OO terms, you can say the following:

Vehicle is the superclass of Car.
Car is the subclass of Vehicle.
Car is the superclass of Subaru.
Subaru is the subclass of Vehicle.
Car inherits from Vehicle.
Subaru inherits from both Vehicle and Car.
Subaru is derived from Car.
Car is derived from Vehicle.
Subaru is derived from Vehicle.
Subaru is a subtype of both Vehicle and Car.

Returning to our IS-A relationship, the following statements are true:

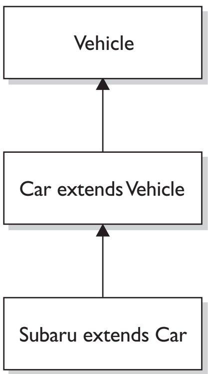
"Car extends Vehicle" means "Car IS-A Vehicle."
"Subaru extends Car" means "Subaru IS-A Car."

And we can also say:

"Subaru IS-A Vehicle" because a class is said to be "a type of" anything further up in its inheritance tree. If the expression (`Foo instanceof Bar`) is `true`, then class `Foo` IS-A `Bar`, even if `Foo` doesn't directly extend `Bar`, but instead extends some other class that is a subclass of `Bar`. Figure 2-2 illustrates the inheritance tree for `Vehicle`, `Car`, and `Subaru`. The arrows move from the subclass to the superclass. In other words, a class' arrow points toward the class from which it extends.

FIGURE 2-2

Inheritance tree for Vehicle, Car, Subaru



HAS-A

HAS-A relationships are based on usage, rather than inheritance. In other words, class A HAS-A B if code in class A has a reference to an instance of class B. For example, you can say the following,

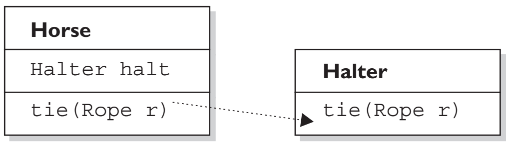
A Horse IS-A Animal. A Horse HAS-A Halter.
The code might look like this:

```
public class Animal { }
public class Horse extends Animal {
   private Halter myHalter;
}
```

In the preceding code, the Horse class has an instance variable of type Halter, so you can say that "Horse HAS-A Halter." In other words, Horse has a reference to a Halter. Horse code can use that Halter reference to invoke methods on the Halter, and get Halter behavior without having Halter-related code (methods) in the Horse class itself. Figure 2-3 illustrates the HAS-A relationship between Horse and Halter.

FIGURE 2-3

HAS-A relationship between Horse and Halter



Horse class has a Halter, because Horse declares an instance variable of type Halter. When code invokes `tie()` on a Horse instance, the Horse invokes `tie()` on the Horse object's Halter instance variable.

HAS-A relationships allow you to design classes that follow good OO practices by not having monolithic classes that do a gazillion different things. Classes (and their resulting objects) should be specialists. As our friend Andrew says, "specialized classes can actually help reduce bugs." The more specialized the class, the more likely it is that you can reuse the class in other applications. If you put all the `Halter`-related code directly into the `Horse` class, you'll end up duplicating code in the `Cow` class, `UnpaidIntern` class, and any other class that might need `Halter` behavior. By keeping the `Halter` code in a separate, specialized `Halter` class, you have the chance to reuse the `Halter` class in multiple applications.

FROM THE CLASSROOM

Object-Oriented Design

IS-A and HAS-A relationships and encapsulation are just the tip of the iceberg when it comes to object-oriented design. Many books and graduate theses have been dedicated to this topic. The reason for the emphasis on proper design is simple: money. The cost to deliver a software application has been estimated to be as much as ten times more expensive for poorly designed programs. Having seen the ramifications of poor designs, I can assure you that this estimate is not far-fetched.

Even the best object-oriented designers make mistakes. It is difficult to visualize the relationships between hundreds, or even thousands, of classes. When mistakes are discovered during the implementation (code writing) phase of a project, the amount of code that has to be rewritten can sometimes cause programming teams to start over from scratch.

The software industry has evolved to aid the designer. Visual object modeling languages, like the Unified Modeling Language (UML), allow designers to design and easily modify classes without having to write code first, because object-oriented components are represented graphically. This allows the designer to create a map of the class relationships and helps them recognize errors before coding begins. Another innovation in object-oriented design is design patterns. Designers noticed that many object-oriented designs apply consistently from project to project, and that it was useful to apply the same designs because it reduced the potential to introduce new design errors. Object-oriented designers then started to share these designs with each other. Now, there are many catalogs of these design patterns both on the Internet and in book form.

Although passing the Java certification exam does not require you to understand object-oriented design this thoroughly, hopefully this background information will help you better appreciate why the test writers chose to include encapsulation, and IS-A, and HAS-A relationships on the exam.

–Jonathan Meeks, Sun Certified Java Programmer

Users of the `Horse` class (that is, code that calls methods on a `Horse` instance), think that the `Horse` class has `Halter` behavior. The `Horse` class might have a `tie(LeadRope rope)` method, for example. Users of the `Horse` class should never have to know that when they invoke the `tie()` method, the `Horse` object turns around and delegates the call to its `Halter` class by invoking `myHalter.tie(rope)`. The scenario just described might look like this:

```
public class Horse extends Animal {
   private Halter myHalter = new Halter();
   public void tie(LeadRope rope) {
      myHalter.tie(rope);  // Delegate tie behavior to the
                           // Halter object
   }
}
public class Halter {
   public void tie(LeadRope aRope) {
      // Do the actual tie work here
   }
}
```

In OO, we don't want callers to worry about which class or which object is actually doing the real work. To make that happen, the `Horse` class hides implementation details from `Horse` users. `Horse` users ask the `Horse` object to do things (in this case, tie itself up), and the `Horse` will either do it or, as in this example, ask something else to do it. To the caller, though, it always appears that the `Horse` object takes care of itself. Users of a `Horse` should not even need to know that there is such a thing as a `Halter` class.

CERTIFICATION OBJECTIVE

Polymorphism (Exam Objective 5.2)

5.2 Given a scenario, develop code that demonstrates the use of polymorphism. Further, determine when casting will be necessary and recognize compiler vs. runtime errors related to object reference casting.

Remember, any Java object that can pass more than one IS-A test can be considered polymorphic. Other than objects of type `Object`, *all* Java objects are polymorphic in that they pass the IS-A test for their own type and for class `Object`.

Remember that the only way to access an object is through a reference variable, and there are a few key things to remember about references:

- A reference variable can be of only one type, and once declared, that type can never be changed (although the object it references can change).
- A reference is a variable, so it can be reassigned to other objects, (unless the reference is declared `final`).
- A reference variable's type determines the methods that can be invoked on the object the variable is referencing.
- A reference variable can refer to any object of the same type as the declared reference, or—this is the big one—**it can refer to any *subtype* of the declared type!**
- A reference variable can be declared as a class type or an interface type. If the variable is declared as an interface type, it can reference any object of any class that *implements* the interface.

Earlier we created a `GameShape` class that was extended by two other classes, `PlayerPiece` and `TilePiece`. Now imagine you want to animate some of the shapes on the game board. But not *all* shapes can be animatable, so what do you do with class inheritance?

Could we create a class with an `animate()` method, and have only *some* of the GameShape subclasses inherit from that class? If we can, then we could have PlayerPiece, for example, extend *both* the GameShape class and Animatable class, while the TilePiece would extend only GameShape. But no, this won't work! Java supports only single inheritance! That means a class can have only one immediate superclass. In other words, if PlayerPiece is a class, there is no way to say something like this:

```
class PlayerPiece extends GameShape, Animatable { // NO!
  // more code
}
```

A *class* cannot *extend* more than one class. That means one parent per class. A class *can* have multiple ancestors, however, since class B could extend class A, and class C could extend class B, and so on. So any given class might have multiple classes up its inheritance tree, but that's not the same as saying a class directly extends two classes.

on the job

Some languages (like C++) allow a class to extend more than one other class. This capability is known as "multiple inheritance." The reason that Java's creators chose not to allow multiple inheritance is that it can become quite messy. In a nutshell, the problem is that if a class extended two other classes, and both superclasses had, say, a doStuff() method, which version of doStuff() would the subclass inherit? This issue can lead to a scenario known as the "Deadly Diamond of Death," because of the shape of the class diagram that can be created in a multiple inheritance design. The diamond is formed when classes B and C both extend A, and both B and C inherit a method from A. If class D extends both B and C, and both B and C have overridden the method in A, class D has, in theory, inherited two different implementations of the same method. Drawn as a class diagram, the shape of the four classes looks like a diamond.

So if that doesn't work, what else could you do? You could simply put the `animate()` code in `GameShape`, and then disable the method in classes that can't be animated. But that's a bad design choice for many reasons, including it's more error-prone, it makes the `GameShape` class less cohesive (more on cohesion in a minute), and it means the `GameShape` API "advertises" that all shapes can be animated, when in fact that's not true since only some of the `GameShape` subclasses will be able to successfully run the `animate()` method.

So what *else* could you do? You already know the answer—create an `Animatable` *interface*, and have only the `GameShape` subclasses that can be animated implement that interface. Here's the interface:

```
public interface Animatable {
   public void animate();
}
```

And here's the modified `PlayerPiece` class that implements the interface:

```
class PlayerPiece extends GameShape implements Animatable {
   public void movePiece() {
     System.out.println("moving game piece");
   }
   public void animate() {
     System.out.println("animating...");
   }
   // more code
}
```

So now we have a `PlayerPiece` that passes the IS-A test for both the `GameShape` class and the `Animatable` interface. That means a `PlayerPiece` can be treated polymorphically as one of four things at any given time, depending on the declared type of the reference variable:

- An `Object` (since any object inherits from `Object`)
- A `GameShape` (since `PlayerPiece` extends `GameShape`)
- A `PlayerPiece` (since that's what it really is)
- An `Animatable` (since `PlayerPiece` implements `Animatable`)

The following are all legal declarations. Look closely:

```
PlayerPiece player = new PlayerPiece();
Object o = player;
GameShape shape = player;
Animatable mover = player;
```

There's only one object here—an instance of type `PlayerPiece`—but there are four different types of reference variables, all referring to that one object on the heap. Pop quiz: which of the preceding reference variables can invoke the `displayShape()` method? Hint: only two of the four declarations can be used to invoke the `displayShape()` method.

Remember that method invocations allowed by the compiler are based solely on the declared type of the reference, regardless of the object type. So looking at the four reference types again—`Object`, `GameShape`, `PlayerPiece`, and `Animatable`—which of these four types know about the `displayShape()` method?

You guessed it—both the `GameShape` class and the `PlayerPiece` class are known (by the compiler) to have a `displayShape()` method, so either of those reference types can be used to invoke `displayShape()`. Remember that to the compiler, a `PlayerPiece` IS-A `GameShape`, so the compiler says, "I see that the declared type is `PlayerPiece`, and since `PlayerPiece` extends `GameShape`, that means `PlayerPiece` inherited the `displayShape()` method. Therefore, `PlayerPiece` can be used to invoke the `displayShape()` method."

Which methods can be invoked when the `PlayerPiece` object is being referred to using a reference declared as type `Animatable`? Only the `animate()` method. Of course the cool thing here is that any class from any inheritance tree can also implement `Animatable`, so that means if you have a method with an argument declared as type `Animatable`, you can pass in `PlayerPiece` objects, `SpinningLogo` objects, and anything else that's an instance of a class that implements `Animatable`. And you can use that parameter (of type `Animatable`) to invoke the `animate()` method, but not the `displayShape()` method (which it might not even have), or anything other than what is known to the compiler based on the reference type. The compiler always knows, though, that you can invoke the methods of class `Object` on any object, so those are safe to call regardless of the reference—class or interface—used to refer to the object.

We've left out one big part of all this, which is that even though the compiler only knows about the declared reference type, the Java Virtual Machine (JVM) at runtime knows what the object really is. And that means that even if the `PlayerPiece` object's `displayShape()` method is called using a `GameShape` reference variable, if the `PlayerPiece` overrides the `displayShape()` method, the JVM will invoke the `PlayerPiece` version! The JVM looks at the real object at the other end of the reference, "sees" that it has overridden the method of the declared reference variable type, and invokes the method of the object's actual class. But one other thing to keep in mind:

Polymorphic method invocations apply only to *instance methods*. You can always refer to an object with a more general reference variable type (a superclass or interface), but at runtime, the ONLY things that are dynamically selected based on the actual *object* (rather than the *reference* type) are instance methods. Not *static* methods. Not *variables*. Only overridden instance methods are dynamically invoked based on the real object's type.

Since this definition depends on a clear understanding of overriding, and the distinction between static methods and instance methods, we'll cover those next.

CERTIFICATION OBJECTIVE

Overriding / Overloading (Exam Objectives 1.5 and 5.4)

1.5 Given a code example, determine if a method is correctly overriding or overloading another method, and identify legal return values (including covariant returns), for the method.

5.4 Given a scenario, develop code that declares and/or invokes overridden or overloaded methods and code that declares and/or invokes superclass, overridden, or overloaded constructors.

Overridden Methods

Any time you have a class that inherits a method from a superclass, you have the opportunity to override the method (unless, as you learned earlier, the method is marked `final`). The key benefit of overriding is the ability to define behavior that's specific to a particular subclass type. The following example demonstrates a Horse subclass of Animal overriding the Animal version of the eat() method:

```
public class Animal {
   public void eat() {
      System.out.println("Generic Animal Eating Generically");
   }
}
class Horse extends Animal {
   public void eat() {
       System.out.println("Horse eating hay, oats, "
                         + "and horse treats");
   }
}
```

For abstract methods you inherit from a superclass, you have no choice. You *must* implement the method in the subclass ***unless the subclass is also abstract.*** Abstract methods must be *implemented* by the concrete subclass, but this is a lot like saying that the concrete subclass *overrides* the abstract methods of the superclass. So you could think of abstract methods as methods you're forced to override.

The `Animal` class creator might have decided that for the purposes of polymorphism, all `Animal` subtypes should have an `eat()` method defined in a unique, specific way. Polymorphically, when someone has an `Animal` reference that refers not to an `Animal` instance, but to an `Animal` subclass instance, the caller should be able to invoke `eat()` on the `Animal` reference, but the actual runtime object (say, a `Horse` instance) will run its own specific `eat()` method. Marking the `eat()` method abstract is the Animal programmer's way of saying to all subclass developers, "It doesn't make any sense for your new subtype to use a generic `eat()` method, so you have to come up with your *own* eat() method implementation!" A (non-abstract), example of using polymorphism looks like this:

```
public class TestAnimals {
  public static void main (String [] args) {
    Animal a = new Animal();
    Animal b = new Horse();  //Animal ref, but a Horse object
    a.eat(); // Runs the Animal version of eat()
    b.eat(); // Runs the Horse version of eat()
  }
}
class Animal {
  public void eat() {
    System.out.println("Generic Animal Eating Generically");
  }
}
class Horse extends Animal {
  public void eat() {
    System.out.println("Horse eating hay, oats, "
                       + "and horse treats");
   }
   public void buck() { }
}
```

In the preceding code, the test class uses an Animal reference to invoke a method on a Horse object. Remember, the compiler will allow only methods in class Animal to be invoked when using a reference to an Animal. The following would not be legal given the preceding code:

```
Animal c = new Horse();
c.buck();  // Can't invoke buck();
           // Animal class doesn't have that method
```

To reiterate, the compiler looks only at the reference type, not the instance type. Polymorphism lets you use a more abstract supertype (including an interface) reference to refer to one of its subtypes (including interface implementers).

The overriding method cannot have a more restrictive access modifier than the method being overridden (for example, you can't override a method marked `public` and make it `protected`). Think about it: if the Animal class advertises a `public` eat() method and someone has an Animal reference (in other words, a reference declared as type Animal), that someone will assume it's safe to call eat() on the Animal reference regardless of the actual instance that the Animal reference is referring to. If a subclass were allowed to sneak in and change the access modifier on the overriding method, then suddenly at runtime—when the JVM invokes the true object's (Horse) version of the method rather than the reference type's (Animal) version—the program would die a horrible death. (Not to mention the emotional distress for the one who was betrayed by the rogue subclass.) Let's modify the polymorphic example we saw earlier in this section:

```
public class TestAnimals {
  public static void main (String [] args) {
    Animal a = new Animal();
    Animal b = new Horse();  //Animal ref, but a Horse object
    a.eat(); // Runs the Animal version of eat()
    b.eat(); // Runs the Horse version of eat()
  }
}
class Animal {
  public void eat() {
    System.out.println("Generic Animal Eating Generically");
  }
}
class Horse extends Animal {
  private void eat() {  // whoa! - it's private!
    System.out.println("Horse eating hay, oats, "
                       + "and horse treats");
  }
}
```

If this code compiled (which it doesn't), the following would fail at runtime:

```
Animal b = new Horse();  // Animal ref, but a Horse
                         // object , so far so good
b.eat();                 // Meltdown at runtime!
```

The variable `b` is of type `Animal`, which has a `public eat()` method. But remember that at runtime, Java uses virtual method invocation to dynamically select the actual version of the method that will run, based on the actual instance. An Animal reference can always refer to a Horse instance, because Horse IS-A(n) Animal. What makes that superclass reference to a subclass instance possible is that the subclass is guaranteed to be able to do everything the superclass can do. Whether the Horse instance overrides the inherited methods of Animal or simply inherits them, anyone with an Animal reference to a Horse instance is free to call all accessible Animal methods. For that reason, an overriding method must fulfill the contract of the superclass.

The rules for overriding a method are as follows:

- The argument list must exactly match that of the overridden method. If they don't match, you can end up with an overloaded method you didn't intend.
- The return type must be the same as, or a subtype of, the return type declared in the original overridden method in the superclass. (More on this in a few pages when we discuss covariant returns.)
- The access level can't be more restrictive than the overridden method's.
- The access level CAN be less restrictive than that of the overridden method.
- Instance methods can be overridden only if they are inherited by the subclass. A subclass within the same package as the instance's superclass can override any superclass method that is not marked `private` or `final`. A subclass in a different package can override only those non-`final` methods marked `public` or `protected` (since `protected` methods are inherited by the subclass).
- The overriding method CAN throw any unchecked (runtime) exception, regardless of whether the overridden method declares the exception. (More in Chapter 5.)
- The overriding method must NOT throw checked exceptions that are new or broader than those declared by the overridden method. For example, a method that declares a FileNotFoundException cannot be overridden by a method that declares a SQLException, Exception, or any other non-runtime exception unless it's a subclass of FileNotFoundException.
- The overriding method can throw narrower or fewer exceptions. Just because an overridden method "takes risks" doesn't mean that the overriding subclass' exception takes the same risks. Bottom line: an overriding method doesn't

have to declare any exceptions that it will never throw, regardless of what the overridden method declares.

- You cannot override a method marked `final`.
- You cannot override a method marked `static`. We'll look at an example in a few pages when we discuss `static` methods in more detail.
- If a method can't be inherited, you cannot override it. Remember that overriding implies that you're reimplementing a method you inherited! For example, the following code is not legal, and even if you added an `eat()` method to Horse, it wouldn't be an override of Animal's `eat()` method.

```
public class TestAnimals {
   public static void main (String [] args) {
      Horse h =  new Horse();
      h.eat(); // Not legal because Horse didn't inherit eat()
   }
}
class Animal {
   private void eat() {
      System.out.println("Generic Animal Eating Generically");
   }
}
class Horse extends Animal { }
```

Invoking a Superclass Version of an Overridden Method

Often, you'll want to take advantage of some of the code in the superclass version of a method, yet still override it to provide some additional specific behavior. It's like saying, "Run the superclass version of the method, then come back down here and finish with my subclass additional method code." (Note that there's no requirement that the superclass version run before the subclass code.) It's easy to do in code using the keyword `super` as follows:

```
public class Animal {
   public void eat() { }
   public void printYourself() {
      // Useful printing code goes here
   }
}
class Horse extends Animal {
   public void printYourself() {
      // Take advantage of Animal code, then add some more
```

```
        super.printYourself();  // Invoke the superclass
                                // (Animal) code
                                // Then do Horse-specific
                                // print work here
    }
}
```

Note: Using `super` to invoke an overridden method only applies to instance methods. (Remember, `static` methods can't be overridden.)

exam watch

If a method is overridden but you use a polymorphic (supertype) reference to refer to the subtype object with the overriding method, the compiler assumes you're calling the supertype version of the method. If the supertype version declares a checked exception, but the overriding subtype method does not, the compiler still thinks you are calling a method that declares an exception (more in Chapter 5). Let's take a look at an example:

```
class Animal {
  public void eat() throws Exception {
    // throws an Exception
  }
}
class Dog2 extends Animal {
  public void eat() { /* no Exceptions */}
  public static void main(String [] args) {
    Animal a = new Dog2();
    Dog2 d = new Dog2();
    d.eat();             // ok
    a.eat();             // compiler error -
                         // unreported exception
  }
}
```

This code will not compile because of the Exception declared on the Animal `eat()` ***method. This happens even though, at runtime, the*** `eat()` ***method used would be the Dog version, which does not declare the exception.***

Examples of Legal and Illegal Method Overrides

Let's take a look at overriding the `eat()` method of Animal:

```
public class Animal {
   public void eat() { }
}
```

Table 2-1 lists examples of illegal overrides of the Animal `eat()` method, given the preceding version of the Animal class.

TABLE 2-1 Examples of Illegal Overrides

Illegal Override Code	Problem with the Code
`private void eat() { }`	Access modifier is more restrictive
`public void eat() throws IOException { }`	Declares a checked exception not defined by superclass version
`public void eat(String food) { }`	A legal overload, not an override, because the argument list changed
`public String eat() { }`	Not an override because of the return type, not an overload either because there's no change in the argument list

Overloaded Methods

You're wondering what overloaded methods are doing in an OO chapter, but we've included them here since one of the things newer Java developers are most confused about are all of the subtle differences between over*loaded* and over*ridden* methods.

Over*loaded* methods let you reuse the same method name in a class, but with different arguments (and optionally, a different return type). Overloading a method often means you're being a little nicer to those who call your methods, because your code takes on the burden of coping with different argument types rather than forcing the caller to do conversions prior to invoking your method. The rules are simple:

- Overloaded methods MUST change the argument list.
- Overloaded methods CAN change the return type.
- Overloaded methods CAN change the access modifier.
- Overloaded methods CAN declare new or broader checked exceptions.

- A method can be overloaded in the *same* class or in a *subclass*. In other words, if class A defines a `doStuff(int i)` method, the subclass B could define a `doStuff(String s)` method without overriding the superclass version that takes an `int`. So two methods with the same name but in different classes can still be considered overloaded, if the subclass inherits one version of the method and then declares another overloaded version in its class definition.

exam watch

Be careful to recognize when a method is overloaded rather than overridden. You might see a method that appears to be violating a rule for overriding, but that is actually a legal overload, as follows:

```
public class Foo {
   public void doStuff(int y, String s) { }
   public void moreThings(int x) { }
}
class Bar extends Foo {
   public void doStuff(int y, long s) throws IOException { }
}
```

It's tempting to see the `IOException` ***as the problem, because the overridden*** `doStuff()` ***method doesn't declare an exception, and*** `IOException` ***is checked by the compiler. But the*** `doStuff()` ***method is not overridden! Subclass*** `Bar` ***overloads the*** `doStuff()` ***method, by varying the argument list, so the*** `IOException` ***is fine.***

Legal Overloads

Let's look at a method we want to overload:

```
public void changeSize(int size, String name, float pattern) { }
```

The following methods are legal overloads of the changeSize() method:

```
public void changeSize(int size, String name) { }
public int changeSize(int size, float pattern) { }
public void changeSize(float pattern, String name)
                       throws IOException { }
```

Invoking Overloaded Methods

Note that there's a lot more to this discussion on how the compiler knows which method to invoke, but the rest is covered in Chapter 3 when we look at boxing and var-args—both of which have a huge impact on overloading. (You still have to pay attention to the part covered here, though.)

When a method is invoked, more than one method of the same name might exist for the object type you're invoking a method on. For example, the Horse class might have three methods with the same name but with different argument lists, which means the method is overloaded.

Deciding which of the matching methods to invoke is based on the arguments. If you invoke the method with a String argument, the overloaded version that takes a String is called. If you invoke a method of the same name but pass it a `float`, the overloaded version that takes a `float` will run. If you invoke the method of the same name but pass it a Foo object, and there isn't an overloaded version that takes a Foo, then the compiler will complain that it can't find a match. The following are examples of invoking overloaded methods:

```
class Adder {
  public int addThem(int x, int y) {
    return x + y;
  }

  // Overload the addThem method to add doubles instead of ints
  public double addThem(double x, double y) {
    return x + y;
  }
}
// From another class, invoke the addThem() method
public class TestAdder {
  public static void main (String [] args) {
    Adder a = new Adder();
    int b = 27;
    int c = 3;
    int result = a.addThem(b,c); // Which addThem is invoked?
    double doubleResult = a.addThem(22.5,9.3); // Which addThem?
   }
}
```

In the preceding TestAdder code, the first call to `a.addThem(b,c)` passes two `ints` to the method, so the first version of `addThem()`—the overloaded version that takes two `int` arguments—is called. The second call to `a.addThem(22.5, 9.3)` passes two `doubles` to the method, so the second version of `addThem()`—the overloaded version that takes two double arguments—is called.

Invoking overloaded methods that take object references rather than primitives is a little more interesting. Say you have an overloaded method such that one version takes an Animal and one takes a Horse (subclass of Animal). If you pass a Horse object in the method invocation, you'll invoke the overloaded version that takes a Horse. Or so it looks at first glance:

```
class Animal { }
class Horse extends Animal { }
class UseAnimals {
   public void doStuff(Animal a) {
      System.out.println("In the Animal version");
   }
   public void doStuff(Horse h) {
      System.out.println("In the Horse version");
   }
   public static void main (String [] args) {
      UseAnimals ua = new UseAnimals();
      Animal animalObj = new Animal();
      Horse horseObj = new Horse();
      ua.doStuff(animalObj);
      ua.doStuff(horseObj);
   }
}
```

The output is what you expect:

```
in the Animal version
in the Horse version
```

But what if you use an Animal reference to a Horse object?

```
Animal animalRefToHorse = new Horse();
 ua.doStuff(animalRefToHorse);
```

Which of the overloaded versions is invoked? You might want to say, "The one that takes a Horse, since it's a Horse object at runtime that's being passed to the method." But that's not how it works. The preceding code would actually print:

```
in the Animal version
```

Even though the actual object at runtime is a Horse and not an Animal, the choice of which overloaded method to call (in other words, the signature of the method) is NOT dynamically decided at runtime. Just remember, the *reference* type (not the object type) determines which overloaded method is invoked! To summarize, which over*ridden* version of the method to call (in other words, from which class in the inheritance tree) is decided at *runtime* based on *object* type, but which over*loaded* version of the method to call is based on the *reference* type of the argument passed at *compile* time. If you invoke a method passing it an Animal reference to a Horse object, the compiler knows only about the Animal, so it chooses the overloaded version of the method that takes an Animal. It does not matter that at runtime there's actually a Horse being passed.

Polymorphism in Overloaded and Overridden Methods

How does polymorphism work with overloaded methods? From what we just looked at, it doesn't appear that polymorphism matters when a method is overloaded. If you pass an Animal reference, the overloaded method that takes an Animal will be invoked, even if the actual object passed is a Horse. Once the Horse masquerading as Animal gets in to the method, however, the Horse object is still a Horse despite being passed into a method expecting an Animal. So it's true that polymorphism doesn't determine which overloaded version is called; polymorphism does come into play when the decision is about which overridden version of a method is called. But sometimes, a method is both overloaded and overridden. Imagine the Animal and Horse classes look like this:

```
public class Animal {
   public void eat() {
      System.out.println("Generic Animal Eating Generically");
   }
}
public class Horse extends Animal {
   public void eat() {
       System.out.println("Horse eating hay ");
   }
   public void eat(String s) {
      System.out.println("Horse eating " + s);
   }
}
```

Notice that the Horse class has both overloaded and overridden the eat() method. Table 2-2 shows which version of the three eat() methods will run depending on how they are invoked.

TABLE 2-2 Examples of Illegal Overrides

Method Invocation Code	Result
`Animal a = new Animal();` `a.eat();`	`Generic Animal Eating Generically`
`Horse h = new Horse();` `h.eat();`	`Horse eating hay`
`Animal ah = new` **`Horse`**`();` `ah.eat();`	`Horse eating hay` Polymorphism works—the actual object type (Horse), not the reference type (Animal), is used to determine which eat() is called.
`Horse he = new Horse();` `he.eat("Apples");`	`Horse eating Apples` The overloaded eat(String s) method is invoked.
`Animal a2 = new Animal();` `a2.eat("treats");`	Compiler error! Compiler sees that Animal class doesn't have an eat() method that takes a String.
`Animal ah2 = new` **`Horse`**`();` `ah2.eat("Carrots");`	Compiler error! Compiler *still* looks only at the reference, and sees that Animal doesn't have an eat() method that takes a String. Compiler doesn't care that the actual object might be a Horse at runtime.

exam watch

Don't be fooled by a method that's overloaded but not overridden by a subclass. It's perfectly legal to do the following:

```
public class Foo {
   void doStuff() { }
}
class Bar extends Foo {
   void doStuff(String s) { }
}
```

The Bar class has two `doStuff()` ***methods: the no-arg version it inherits from Foo (and does not override), and the overloaded*** `doStuff(String s)` ***defined in the Bar class. Code with a reference to a Foo can invoke only the no-arg version, but code with a reference to a Bar can invoke either of the overloaded versions.***

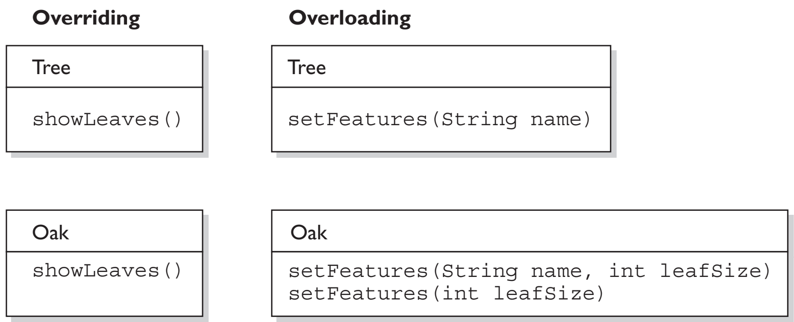
Table 2-3 summarizes the difference between overloaded and overridden methods.

TABLE 2-3 Differences Between Overloaded and Overridden Methods

	Overloaded Method	Overridden Method
Argument(s)	Must change.	Must not change.
Return type	Can change.	Can't change except for covariant returns.
Exceptions	Can change.	Can reduce or eliminate. Must not throw new or broader checked exceptions.
Access	Can change.	Must not make more restrictive (can be less restrictive).
Invocation	*Reference* type determines which overloaded version (based on declared argument types) is selected. Happens at *compile* time. The actual *method* that's invoked is still a virtual method invocation that happens at runtime, but the compiler will already know the *signature* of the method to be invoked. So at runtime, the argument match will already have been nailed down, just not the *class* in which the method lives.	*Object* type (in other words, *the type of the actual instance on the heap*) determines which method is selected. Happens at *runtime*.

The current objective (5.4) covers both method and constructor overloading, but we'll cover constructor overloading in the next section, where we'll also cover the other constructor-related topics that are on the exam. Figure 2-4 illustrates the way overloaded and overridden methods appear in class relationships.

FIGURE 2-4 Overloaded and overridden methods in class relationships



CERTIFICATION OBJECTIVE

Reference Variable Casting (Objective 5.2)

5.2 Given a scenario, develop code that demonstrates the use of polymorphism. Further, determine when casting will be necessary and recognize compiler vs. runtime errors related to object reference casting.

We've seen how it's both possible and common to use generic reference variable types to refer to more specific object types. It's at the heart of polymorphism. For example, this line of code should be second nature by now:

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

But what happens when you want to use that `animal` reference variable to invoke a method that only class `Dog` has? You know it's referring to a `Dog`, and you want to do a `Dog`-specific thing? In the following code, we've got an array of `Animals`, and whenever we find a `Dog` in the array, we want to do a special `Dog` thing. Let's agree for now that all of this code is OK, except that we're not sure about the line of code that invokes the `playDead` method.

```
class Animal {
  void makeNoise() {System.out.println("generic noise"); }
}
class Dog extends Animal {
  void makeNoise() {System.out.println("bark"); }
  void playDead() { System.out.println("roll over"); }
}

class CastTest2 {
  public static void main(String [] args) {
    Animal [] a = {new Animal(), new Dog(), new Animal() };
    for(Animal animal : a) {
      animal.makeNoise();
      if(animal instanceof Dog) {
        animal.playDead();       // try to do a Dog behavior ?
      }
    }
  }
}
```

When we try to compile this code, the compiler says something like this:

```
cannot find symbol
```

The compiler is saying, "Hey, class Animal doesn't have a `playDead()` method". Let's modify the `if` code block:

```
if(animal instanceof Dog) {
  Dog d = (Dog) animal;      // casting the ref. var.
  d.playDead();
}
```

The new and improved code block contains a cast, which in this case is sometimes called a *downcast*, because we're casting down the inheritance tree to a more specific class. Now, the compiler is happy. Before we try to invoke `playDead`, we cast the animal variable to type `Dog`. What we're saying to the compiler is, "We know it's really referring to a `Dog` object, so it's okay to make a new `Dog` reference variable to refer to that object." In this case we're safe because before we ever try the cast, we do an `instanceof` test to make sure.

It's important to know that the compiler is forced to trust us when we do a downcast, even when we screw up:

```
class Animal { }
class Dog extends Animal { }
class DogTest {
  public static void main(String [] args) {
    Animal animal = new Animal();
    Dog d = (Dog) animal;          // compiles but fails later
  }
}
```

It can be maddening! This code compiles! When we try to run it, we'll get an exception something like this:

```
java.lang.ClassCastException
```

Why can't we trust the compiler to help us out here? Can't it see that `animal` is of type `Animal`? All the compiler can do is verify that the two types are in the same inheritance tree, so that depending on whatever code might have come before the downcast, it's possible that `animal` is of type `Dog`. The compiler must allow things that might possibly work at runtime. However, if the compiler knows with certainty that the cast could not possibly work, compilation will fail. The following replacement code block will NOT compile:

```
Animal animal = new Animal();
Dog d = (Dog) animal;
String s = (String) animal;  // animal can't EVER be a String
```

In this case, you'll get an error something like this:

```
inconvertible types
```

Unlike downcasting, upcasting (casting *up* the inheritance tree to a more general type) works implicitly (i.e., you don't have to type in the cast) because when you upcast you're implicitly restricting the number of methods you can invoke, as opposed to *down*casting, which implies that later on, you might want to invoke a more *specific* method. For instance:

```
class Animal { }
class Dog extends Animal { }

class DogTest {
  public static void main(String [] args) {
    Dog d = new Dog();
    Animal a1 = d;           // upcast ok with no explicit cast
    Animal a2 = (Animal) d;  // upcast ok with an explicit cast
  }
}
```

Both of the previous upcasts will compile and run without exception, because a Dog IS-A Animal, which means that anything an Animal can do, a Dog can do. A Dog can do more, of course, but the point is—anyone with an Animal reference can safely call Animal methods on a Dog instance. The Animal methods may have been overridden in the Dog class, but all we care about now is that a Dog can always do at least everything an Animal can do. The compiler and JVM know it too, so the implicit upcast is always legal for assigning an object of a subtype to a reference of one of its supertype classes (or interfaces). If Dog implements Pet, and Pet defines `beFriendly()`, then a Dog can be implicitly cast to a Pet, but the only Dog method you can invoke then is `beFriendly()`, which Dog was forced to implement because Dog implements the Pet interface.

One more thing…if `Dog implements Pet`, then if `Beagle extends Dog`, but Beagle does not *declare* that it implements Pet, Beagle is still a Pet! Beagle is a Pet simply because it extends Dog, and Dog's already taken care of the Pet parts of itself, and all its children. The Beagle class can always override any methods it inherits from Dog, including methods that Dog implemented to fulfill its interface contract.

And just one more thing…if Beagle does declare it implements Pet, just so that others looking at the Beagle class API can easily see that Beagle IS-A Pet, without having to look at Beagle's superclasses, Beagle still doesn't need to implement the beFriendly() method if the Dog class (Beagle's superclass) has already taken care of that. In other words, if Beagle IS-A Dog, and Dog IS-A Pet, then Beagle IS-A Pet, and has already met its Pet obligations for implementing the `beFriendly()` method since it inherits the `beFriendly()` method. The compiler is smart enough to say, "I know Beagle already IS a Dog, but it's OK to make it more obvious."

So don't be fooled by code that shows a concrete class that declares that it implements an interface, but doesn't implement the *methods* of the interface. Before you can tell whether the code is legal, you must know what the superclasses of this implementing class have declared. If any superclass in its inheritance tree has already provided concrete (i.e., non-abstract) method implementations, then, regardless of whether the superclass declares that it implements the interface, the subclass is under no obligation to re-implement (override) those methods.

exam watch

The exam creators will tell you that they're forced to jam tons of code into little spaces "because of the exam engine." While that's partially true, they ALSO like to obfuscate. The following code:

```
Animal a = new Dog();
Dog d = (Dog) a;
d.doDogStuff();
```

Can be replaced with this easy-to-read bit of fun:

```
Animal a = new Dog();
((Dog)a).doDogStuff();
```

In this case the compiler needs all of those parentheses, otherwise it thinks it's been handed an incomplete statement.

CERTIFICATION OBJECTIVE

Implementing an Interface (Exam Objective 1.2)

1.2 Develop code that declares an interface…

When you implement an interface, you're agreeing to adhere to the contract defined in the interface. That means you're agreeing to provide legal implementations for every method defined in the interface, and that anyone who knows what the interface methods look like (not how they're implemented, but how they can be called and what they return) can rest assured that they can invoke those methods on an instance of your implementing class.

For example, if you create a class that implements the Runnable interface (so that your code can be executed by a specific thread), you must provide the `public void run()` method. Otherwise, the poor thread could be told to go execute your Runnable object's code and—surprise surprise—the thread then discovers the object has no `run()` method! (At which point, the thread would blow up and the JVM would crash in a spectacular yet horrible explosion.) Thankfully, Java prevents this meltdown from occurring by running a compiler check on any class that claims to implement an interface. If the class says it's implementing an interface, it darn well better have an implementation for each method in the interface (with a few exceptions we'll look at in a moment).

Assuming an interface, Bounceable, with two methods: `bounce()`, and `setBounceFactor()`, the following class will compile:

```
public class Ball implements Bounceable {  // Keyword
                                           // 'implements'
   public void bounce() { }
   public void setBounceFactor(int bf) { }
}
```

OK, we know what you're thinking: "This has got to be the worst implementation class in the history of implementation classes." It compiles, though. And runs. The interface contract guarantees that a class will have the method (in other words, others can call the method subject to access control), but it never guaranteed a good implementation—or even any actual implementation code in the body of the method. The compiler will never say to you, "Um, excuse me, but did you really mean to put nothing between those curly braces? HELLO. This is a method after all, so shouldn't it do something?"

Implementation classes must adhere to the same rules for method implementation as a class extending an `abstract` class. In order to be a legal implementation class, a nonabstract implementation class must do the following:

- Provide concrete (nonabstract) implementations for all methods from the declared interface.
- Follow all the rules for legal overrides.
- Declare no checked exceptions on implementation methods other than those declared by the interface method, or subclasses of those declared by the interface method.
- Maintain the signature of the interface method, and maintain the same return type (or a subtype). (But it does not have to declare the exceptions declared in the interface method declaration.)

But wait, there's more! An implementation class can itself be `abstract`! For example, the following is legal for a class Ball implementing Bounceable:

```
abstract class Ball implements Bounceable { }
```

Notice anything missing? We never provided the implementation methods. And that's OK. If the implementation class is `abstract`, it can simply pass the buck to its first concrete subclass. For example, if class BeachBall extends Ball, and BeachBall is not `abstract`, then BeachBall will have to provide all the methods from Bounceable:

```
class BeachBall extends Ball {
  // Even though we don't say it in the class declaration above,
  // BeachBall implements Bounceable, since BeachBall's abstract
  // superclass (Ball) implements Bounceable

   public void bounce() {
      // interesting BeachBall-specific bounce code
   }
   public void setBounceFactor(int bf) {
      // clever BeachBall-specific code for setting
      // a bounce factor
   }
```

```
    // if class Ball defined any abstract methods,
    // they'll have to be
    // implemented here as well.
}
```

Look for classes that claim to implement an interface but don't provide the correct method implementations. Unless the implementing class is abstract, the implementing class must provide implementations for all methods defined in the interface.

Two more rules you need to know and then we can put this topic to sleep (or put you to sleep; we always get those two confused):

1. A class can implement more than one interface. It's perfectly legal to say, for example, the following:

```
public class Ball implements Bounceable, Serializable, Runnable
{ ... }
```

You can extend only one class, but implement many interfaces. But remember that subclassing defines who and what you are, whereas implementing defines a role you can play or a hat you can wear, despite how different you might be from some other class implementing the same interface (but from a different inheritance tree). For example, a Person extends HumanBeing (although for some, that's debatable). But a Person may also implement Programmer, Snowboarder, Employee, Parent, or PersonCrazyEnoughToTakeThisExam.

2. An interface can itself extend another interface, but never implement anything. The following code is perfectly legal:

```
public interface Bounceable extends Moveable { }   // ok!
```

What does that mean? The first concrete (nonabstract) implementation class of Bounceable must implement all the methods of Bounceable, plus all the methods of Moveable! The subinterface, as we call it, simply adds more requirements to the contract of the superinterface. You'll see this concept applied in many areas of Java, especially J2EE where you'll often have to build your own interface that extends one of the J2EE interfaces.

Hold on though, because here's where it gets strange. An interface can extend more than one interface! Think about that for a moment. You know that when we're talking about classes, the following is illegal:

```
public class Programmer extends Employee, Geek { } // Illegal!
```

As we mentioned earlier, a class is not allowed to extend multiple classes in Java. An interface, however, is free to extend multiple interfaces.

```
interface Bounceable extends Moveable, Spherical {   // ok!
   void bounce();
   void setBounceFactor(int bf);
}
interface Moveable {
   void moveIt();
}
interface Spherical {
   void doSphericalThing();
}
```

In the next example, Ball is required to implement Bounceable, plus all methods from the interfaces that Bounceable extends (including any interfaces those interfaces extend, and so on until you reach the top of the stack—or is it the bottom of the stack?). So Ball would need to look like the following:

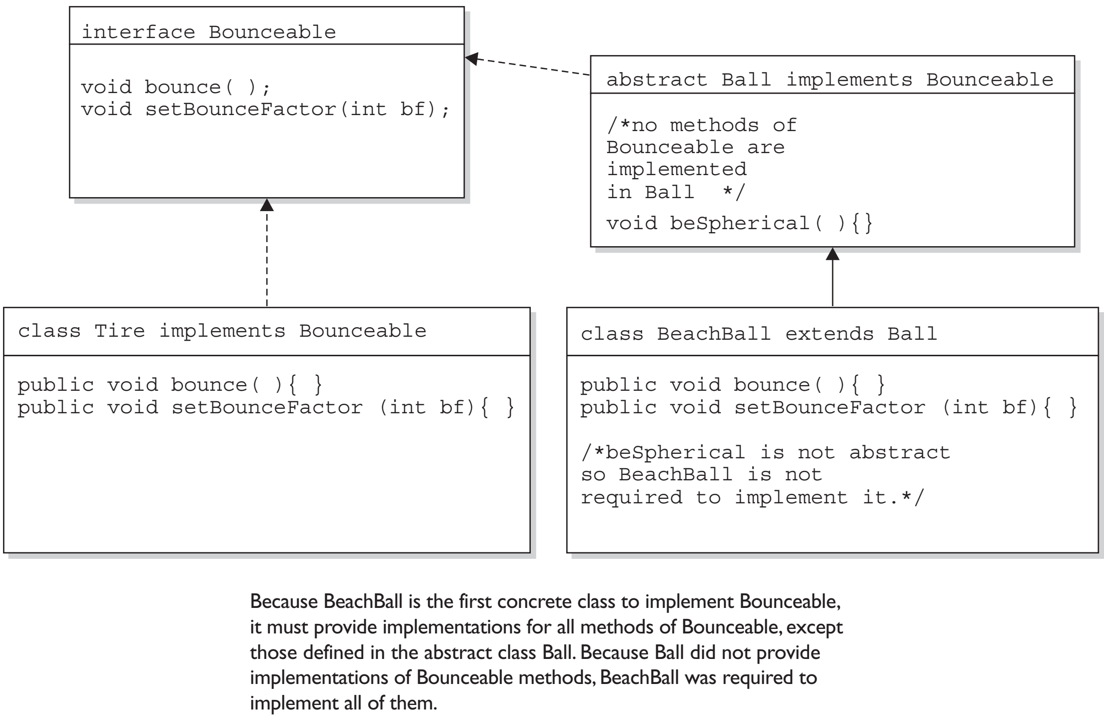
```
class Ball implements Bounceable {

   public void bounce() { }   // Implement Bounceable's methods
   public void setBounceFactor(int bf) { }

   public void moveIt() { }    // Implement Moveable's method

   public void doSphericalThing() { }   // Implement Spherical
}
```

If class Ball fails to implement any of the methods from Bounceable, Moveable, or Spherical, the compiler will jump up and down wildly, red in the face, until it does. Unless, that is, class Ball is marked `abstract`. In that case, Ball could choose to implement any, all, or none of the methods from any of the interfaces, thus leaving the rest of the implementations to a concrete subclass of Ball, as follows:

```
abstract class Ball implements Bounceable {
   public void bounce() { ... }  // Define bounce behavior
   public void setBounceFactor(int bf) { ... }
   // Don't implement the rest; leave it for a subclass
}
class SoccerBall extends Ball {  // class SoccerBall must
             // implement the interface methods that Ball didn't
   public void moveIt() { ... }
   public void doSphericalThing() { ... }
   // SoccerBall can choose to override the Bounceable methods
   // implemented by Ball
   public void bounce() { ... }
}
```

Figure 2-5 compares concrete and abstract examples of extends and implements, for both classes and interfaces.

FIGURE 2-5 Comparing concrete and abstract examples of extends and implements



exam watch

Look for illegal uses of extends and implements. The following shows examples of legal and illegal class and interface declarations:

```
class Foo { }                        // OK
class Bar implements Foo  { }        // No! Can't implement a class
interface Baz { }                    // OK
interface Fi { }                     // OK
interface Fee implements Baz { }     // No! Interface can't
                                     // implement an interface
interface Zee implements Foo { }     // No! Interface can't
                                     // implement a class
interface Zoo extends Foo { }        // No! Interface can't
                                     // extend a class
interface Boo extends Fi { }         // OK. Interface can extend
                                     // an interface
class Toon extends Foo, Button { }   // No! Class can't extend
                                     // multiple classes
class Zoom implements Fi, Baz { }    // OK. class can implement
                                     // multiple interfaces
interface Vroom extends Fi, Baz { }  // OK. interface can extend
                                     // multiple interfaces
class Yow extends Foo implements Fi { } // OK. Class can do both
                                        // (extends must be 1st)
```

Burn these in, and watch for abuses in the questions you get on the exam. Regardless of what the question appears to be testing, the real problem might be the class or interface declaration. Before you get caught up in, say, tracing a complex threading flow, check to see if the code will even compile. (Just that tip alone may be worth your putting us in your will!) (You'll be impressed by the effort the exam developers put into distracting you from the real problem.) (How did people manage to write anything before parentheses were invented?)

CERTIFICATION OBJECTIVE

Legal Return Types (Exam Objective 1.5)

1.5 Given a code example, determine if a method is correctly overriding or overloading another method, and identify legal return values (including covariant returns), for the method.

This objective covers two aspects of return types: what you can declare as a return type, and what you can actually return as a value. What you can and cannot declare is pretty straightforward, but it all depends on whether you're overriding an inherited method or simply declaring a new method (which includes overloaded methods). We'll take just a quick look at the difference between return type rules for overloaded and overriding methods, because we've already covered that in this chapter. We'll cover a small bit of new ground, though, when we look at polymorphic return types and the rules for what is and is not legal to actually return.

Return Type Declarations

This section looks at what you're allowed to declare as a return type, which depends primarily on whether you are overriding, overloading, or declaring a new method.

Return Types on Overloaded Methods

Remember that method overloading is not much more than name reuse. The overloaded method is a completely different method from any other method of the same name. So if you inherit a method but overload it in a subclass, you're not subject to the restrictions of overriding, which means you can declare any return type you like. What you can't do is change *only* the return type. To overload a method, remember, you must change the argument list. The following code shows an overloaded method:

```
public class Foo{
   void go() { }
}
public class Bar extends Foo {
   String go(int x) {
```

```
      return null;
    }
}
```

Notice that the Bar version of the method uses a different return type. That's perfectly fine. As long as you've changed the argument list, you're overloading the method, so the return type doesn't have to match that of the superclass version. What you're NOT allowed to do is this:

```
public class Foo{
   void go() { }
}
public class Bar extends Foo {
   String go() { // Not legal! Can't change only the return type
      return null;
   }
}
```

Overriding and Return Types, and Covariant Returns

When a subclass wants to change the method implementation of an inherited method (an override), the subclass must define a method that matches the inherited version exactly. Or, as of Java 5, you're allowed to change the return type in the overriding method as long as the new return type is a *subtype* of the declared return type of the overridden (superclass) method.

Let's look at a covariant return in action:

```
class Alpha {
  Alpha doStuff(char c) {
    return new Alpha();
  }
}

class Beta extends Alpha {
  Beta doStuff(char c) {     // legal override in Java 1.5
    return new Beta();
  }
}
```

As of Java 5, this code will compile. If you were to attempt to compile this code with a 1.4 compiler or with the source flag as follows:

```
javac -source 1.4 Beta.java
```

you would get a compiler error something like this:

```
attempting to use incompatible return type
```

(We'll talk more about compiler flags in Chapter 10.)

Other rules apply to overriding, including those for access modifiers and declared exceptions, but those rules aren't relevant to the return type discussion.

For the exam, be sure you know that overloaded methods can change the return type, but overriding methods can do so only within the bounds of covariant returns. Just that knowledge alone will help you through a wide range of exam questions.

Returning a Value

You have to remember only six rules for returning a value:

1. You can return `null` in a method with an object reference return type.

```
public Button doStuff() {
  return null;
}
```

2. An array is a perfectly legal return type.

```
public String[] go() {
  return new String[] {"Fred", "Barney", "Wilma"};
}
```

3. In a method with a primitive return type, you can return any value or variable that can be implicitly converted to the declared return type.

```
public int foo() {
  char c = 'c';
  return c;  // char is compatible with int
}
```

4. In a method with a primitive return type, you can return any value or variable that can be explicitly cast to the declared return type.

```
public int foo () {
  float f = 32.5f;
  return (int) f;
}
```

5. You must *not* return anything from a method with a void return type.

```
public void bar() {
  return "this is it";  // Not legal!!
}
```

6. In a method with an object reference return type, you can return any object type that can be implicitly cast to the declared return type.

```
public Animal getAnimal() {
  return new Horse();  // Assume Horse extends Animal
}

public Object getObject() {
  int[] nums = {1,2,3};
  return nums;  // Return an int array,
                 // which is still an object
}

public interface Chewable { }
public class Gum implements Chewable { }

public class TestChewable {
    // Method with an interface return type
    public Chewable getChewable() {
      return new Gum();  // Return interface implementer
   }
}
```

exam watch

Watch for methods that declare an abstract class or interface return type, and know that any object that passes the IS-A test (in other words, would test true using the instanceof operator) can be returned from that method— for example:

```
public abstract class Animal { }
public class Bear extends Animal { }
public class Test {
   public Animal go() {
      return new Bear();  // OK, Bear "is-a" Animal
   }
}
```

This code will compile, the return value is a subtype.

CERTIFICATION OBJECTIVE

Constructors and Instantiation (Exam Objectives 1.6, 5.3, and 5.4)

1.6 Given a set of classes and superclasses, develop constructors for one or more of the classes. Given a class declaration, determine if a default constructor will be created, and if so, determine the behavior of that constructor. Given a nested or nonnested class listing, write code to instantiate the class.

5.3 Explain the effect of modifiers on inheritance with respect to constructors, instance or static variables, and instance or static methods.

5.4 Given a scenario, develop code that declares and/or invokes overridden or overloaded methods and code that declares and/or invokes superclass, overridden, or overloaded constructors.

Objects are constructed. You can't make a new object without invoking a constructor. In fact, you can't make a new object without invoking not just the constructor of the object's actual class type, but also the constructor of each of its superclasses! Constructors are the code that runs whenever you use the keyword `new`. OK, to be a bit more accurate, there can also be initialization blocks that run when you say `new`, but we're going to cover them (init blocks), and their static initialization counterparts, in the next chapter. We've got plenty to talk about here—we'll look at how constructors are coded, who codes them, and how they work at runtime. So grab your hardhat and a hammer, and let's do some object building.

Constructor Basics

Every class, *including abstract classes*, MUST have a constructor. Burn that into your brain. But just because a class must have one, doesn't mean the programmer has to type it. A constructor looks like this:

```
class Foo {
   Foo() { } // The constructor for the Foo class
}
```

Notice what's missing? There's no return type! Two key points to remember about constructors are that they have no return type and their names must exactly match the class name. Typically, constructors are used to initialize instance variable state, as follows:

```
class Foo {
   int size;
   String name;
   Foo(String name, int size) {
      this.name = name;
      this.size = size;
   }
}
```

In the preceding code example, the Foo class does not have a no-arg constructor. That means the following will fail to compile:

```
Foo f = new Foo();  // Won't compile, no matching constructor
```

but the following will compile:

```
Foo f = new Foo("Fred", 43);  // No problem. Arguments match
                              // the Foo constructor.
```

So it's very common (and desirable) for a class to have a no-arg constructor, regardless of how many other overloaded constructors are in the class (yes, constructors can be overloaded). You can't always make that work for your classes; occasionally you have a class where it makes no sense to create an instance without supplying information to the constructor. A `java.awt.Color` object, for example, can't be created by calling a no-arg constructor, because that would be like saying to the JVM, "Make me a new Color object, and I really don't care what color it is...you pick." Do you seriously want the JVM making your style decisions?

Constructor Chaining

We know that constructors are invoked at runtime when you say `new` on some class type as follows:

```
Horse h = new Horse();
```

But what *really* happens when you say `new Horse()` ?
(Assume Horse extends Animal and Animal extends Object.)

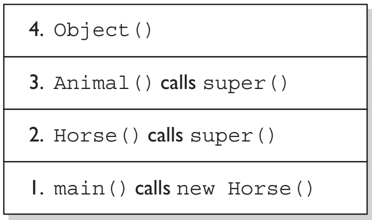
1. Horse constructor is invoked. Every constructor invokes the constructor of its superclass with an (implicit) call to super(), unless the constructor invokes an overloaded constructor of the same class (more on that in a minute).
2. Animal constructor is invoked (Animal is the superclass of Horse).
3. Object constructor is invoked (Object is the ultimate superclass of all classes, so class Animal extends Object even though you don't actually type "extends Object" into the Animal class declaration. It's implicit.) At this point we're on the top of the stack.
4. Object instance variables are given their explicit values. By *explicit* values, we mean values that are assigned at the time the variables are declared, like "`int x = 27`", where "`27`" is the explicit value (as opposed to the default value) of the instance variable.
5. Object constructor completes.
6. Animal instance variables are given their explicit values (if any).
7. Animal constructor completes.

8. Horse instance variables are given their explicit values (if any).
9. Horse constructor completes.

Figure 2-6 shows how constructors work on the call stack.

FIGURE 2-6

Constructors on the call stack



Rules for Constructors

The following list summarizes the rules you'll need to know for the exam (and to understand the rest of this section). You MUST remember these, so be sure to study them more than once.

- Constructors can use any access modifier, including private. (A private constructor means only code within the class itself can instantiate an object of that type, so if the `private` constructor class wants to allow an instance of the class to be used, the class must provide a static method or variable that allows access to an instance created from within the class.)
- The constructor name must match the name of the class.
- Constructors must not have a return type.
- It's legal (but stupid) to have a method with the same name as the class, but that doesn't make it a constructor. If you see a return type, it's a method rather than a constructor. In fact, you could have both a method and a constructor with the same name—the name of the class—in the same class, and that's not a problem for Java. Be careful not to mistake a method for a constructor—be sure to look for a return type.
- If you don't type a constructor into your class code, a default constructor will be automatically generated by the compiler.
- The default constructor is ALWAYS a no-arg constructor.
- If you want a no-arg constructor and you've typed any other constructor(s) into your class code, the compiler won't provide the no-arg constructor (or

any other constructor) for you. In other words, if you've typed in a constructor with arguments, you won't have a no-arg constructor unless you type it in yourself!

- Every constructor has, as its first statement, either a call to an overloaded constructor (this()) or a call to the superclass constructor (super()), although remember that this call can be inserted by the compiler.
- If you do type in a constructor (as opposed to relying on the compiler-generated default constructor), and you do not type in the call to super() or a call to this(), the compiler will insert a no-arg call to super() for you, as the very first statement in the constructor.
- A call to super() can be either a no-arg call or can include arguments passed to the super constructor.
- A no-arg constructor is not necessarily the default (i.e., compiler-supplied) constructor, although the default constructor is always a no-arg constructor. The default constructor is the one the compiler provides! While the default constructor is always a no-arg constructor, you're free to put in your own no-arg constructor.
- You cannot make a call to an instance method, or access an instance variable, until after the super constructor runs.
- Only static variables and methods can be accessed as part of the call to `super()` or `this()`. (Example: super(Animal.NAME) is OK, because NAME is declared as a static variable.)
- Abstract classes have constructors, and those constructors are always called when a concrete subclass is instantiated.
- Interfaces do not have constructors. Interfaces are not part of an object's inheritance tree.
- The only way a constructor can be invoked is from within another constructor. In other words, you can't write code that actually calls a constructor as follows:

```
class Horse {
  Horse() { } // constructor
  void doStuff() {
    Horse();  // calling the constructor - illegal!
  }
}
```

Determine Whether a Default Constructor Will Be Created

The following example shows a Horse class with two constructors:

```
class Horse {
   Horse() { }
   Horse(String name) { }
 }
```

Will the compiler put in a default constructor for the class above? No!
How about for the following variation of the class?

```
class Horse {
   Horse(String name) { }
}
```

Now will the compiler insert a default constructor? No!
What about this class?

```
class Horse { }
```

Now we're talking. The compiler will generate a default constructor for the preceding class, because the class doesn't have any constructors defined.
OK, what about this class?

```
class Horse {
   void Horse() { }
}
```

It might look like the compiler won't create one, since there already is a constructor in the Horse class. Or is there? Take another look at the preceding Horse class.

What's wrong with the Horse() constructor? It isn't a constructor at all! It's simply a method that happens to have the same name as the class. Remember, the return type is a dead giveaway that we're looking at a method, and not a constructor.

How do you know for sure whether a default constructor will be created?
Because you didn't write any constructors in your class.

How do you know what the default constructor will look like?

Because...

- The default constructor has the same access modifier as the class.
- The default constructor has no arguments.
- The default constructor includes a no-arg call to the super constructor (`super()`).

Table 2-4 shows what the compiler will (or won't) generate for your class.

What happens if the super constructor has arguments?

Constructors can have arguments just as methods can, and if you try to invoke a method that takes, say, an int, but you don't pass anything to the method, the compiler will complain as follows:

```
class Bar {
    void takeInt(int x) { }
}

class UseBar {
   public static void main (String [] args) {
     Bar b = new Bar();
     b.takeInt();  // Try to invoke a no-arg takeInt() method
   }
}
```

The compiler will complain that you can't invoke takeInt() without passing an int. Of course, the compiler enjoys the occasional riddle, so the message it spits out on some versions of the JVM (your mileage may vary) is less than obvious:

```
UseBar.java:7: takeInt(int) in Bar cannot be applied to ()
     b.takeInt();
      ^
```

But you get the idea. The bottom line is that there must be a match for the method. And by match, we mean that the argument types must be able to accept the values or variables you're passing, and in the order you're passing them. Which brings us back to constructors (and here you were thinking we'd never get there), which work exactly the same way.

TABLE 2-4 Compiler-Generated Constructor Code

Class Code (What You Type)	Compiler Generated Constructor Code (in Bold)

class Foo { }	class Foo {
	  Foo() {
	    super();
	  }
	}

class Foo {
  Foo() { }
}
	class Foo {
	  Foo() {
	    super();
	  }
	}

public class Foo { }	public class Foo {
	  public Foo() {
	    super();
	  }
	}

class Foo {
  Foo(String s) { }
}
	class Foo {
	  Foo(String s) {
	    super();
	  }
	}

class Foo {
  Foo(String s) {
    super();
  }
}
	Nothing, compiler doesn't need to insert anything.

class Foo {
  void Foo() { }
}
	class Foo {
	  void Foo() { }
	  Foo() {
	    super();
	  }
	}
	(void Foo() *is a method, not a constructor.*)

So if your super constructor (that is, the constructor of your immediate superclass/parent) has arguments, you must type in the call to super(), supplying the appropriate arguments. Crucial point: if your superclass does not have a no-arg constructor, you must type a constructor in your class (the subclass) because you need a place to put in the call to super with the appropriate arguments.

The following is an example of the problem:

```
class Animal {
   Animal(String name) { }
}

class Horse extends Animal {
   Horse() {
      super();  // Problem!
   }
}
```

And once again the compiler treats us with the stunningly lucid:

```
Horse.java:7: cannot resolve symbol
symbol  : constructor Animal  ()
location: class Animal
      super();  // Problem!
      ^
```

If you're lucky (and it's a full moon), *your* compiler might be a little more explicit. But again, the problem is that there just isn't a match for what we're trying to invoke with `super()`—an Animal constructor with no arguments.

Another way to put this is that if your superclass does *not* have a no-arg constructor, then in your subclass you will not be able to use the default constructor supplied by the compiler. It's that simple. Because the compiler can *only* put in a call to a no-arg `super()`, you won't even be able to compile something like this:

```
class Clothing {
   Clothing(String s) { }
}
class TShirt extends Clothing { }
```

Trying to compile this code gives us exactly the same error we got when we put a constructor in the subclass with a call to the no-arg version of super():

```
Clothing.java:4: cannot resolve symbol
symbol  : constructor Clothing  ()
location: class Clothing
```

```
class TShirt extends Clothing { }
^
```

In fact, the preceding Clothing and TShirt code is implicitly the same as the following code, where we've supplied a constructor for TShirt that's identical to the default constructor supplied by the compiler:

```
class Clothing {
   Clothing(String s) { }
}
class TShirt extends Clothing {
                  // Constructor identical to compiler-supplied
                  // default constructor
   TShirt() {
      super(); // Won't work!
   }           // Invokes a no-arg Clothing() constructor,
}              // but there isn't one!
```

One last point on the whole default constructor thing (and it's probably very obvious, but we have to say it or we'll feel guilty for years), ***constructors are never inherited.*** They aren't methods. They can't be overridden (because they aren't methods and only instance methods can be overridden). So the type of constructor(s) your superclass has in no way determines the type of default constructor you'll get. Some folks mistakenly believe that the default constructor somehow matches the super constructor, either by the arguments the default constructor will have (remember, the default constructor is always a no-arg), or by the arguments used in the compiler-supplied call to `super()`.

So, although constructors can't be overridden, you've already seen that they can be overloaded, and typically are.

Overloaded Constructors

Overloading a constructor means typing in multiple versions of the constructor, each having a different argument list, like the following examples:

```
class Foo {
   Foo() { }
   Foo(String s) { }
}
```

The preceding Foo class has two overloaded constructors, one that takes a string, and one with no arguments. Because there's no code in the no-arg version, it's actually identical to the default constructor the compiler supplies, but remember—since there's already a constructor in this class (the one that takes a string), the compiler won't supply a default constructor. If you want a no-arg constructor to overload the with-args version you already have, you're going to have to type it yourself, just as in the Foo example.

Overloading a constructor is typically used to provide alternate ways for clients to instantiate objects of your class. For example, if a client knows the animal name, they can pass that to an Animal constructor that takes a string. But if they don't know the name, the client can call the no-arg constructor and that constructor can supply a default name. Here's what it looks like:

```
public class Animal {
  String name;
  Animal(String name) {
    this.name = name;
  }

  Animal() {
    this(makeRandomName());
  }

  static String makeRandomName() {
    int x = (int) (Math.random() * 5);
    String name = new String[] {"Fluffy", "Fido",
                                "Rover", "Spike",
                                "Gigi"}[x];
    return name;
  }

  public static void main (String [] args) {
    Animal a = new Animal();
    System.out.println(a.name);
    Animal b = new Animal("Zeus");
    System.out.println(b.name);
  }
}
```

Running the code four times produces this output:

```
% java Animal
Gigi
Zeus

% java Animal
Fluffy
Zeus

% java Animal
Rover
Zeus

% java Animal
Fluffy
Zeus
```

There's a lot going on in the preceding code. Figure 2-7 shows the call stack for constructor invocations when a constructor is overloaded. Take a look at the call stack, and then let's walk through the code straight from the top.

FIGURE 2-7

Overloaded constructors on the call stack

4. `Object()`
3. `Animal(String s)` calls `super()`
2. `Animal()` calls `this(randomlyChosenNameString)`
1. `main()` calls `new Animal()`

- **Line 2** Declare a String instance variable name.
- **Lines 3–5** Constructor that takes a String, and assigns it to instance variable name.
- **Line 7** Here's where it gets fun. Assume every animal needs a name, but the client (calling code) might not always know what the name should be, so you'll assign a random name. The no-arg constructor generates a name by invoking the makeRandomName() method.
- **Line 8** The no-arg constructor invokes its own overloaded constructor that takes a String, in effect calling it the same way it would be called if

client code were doing a `new` to instantiate an object, passing it a String for the name. The overloaded invocation uses the keyword `this`, but uses it as though it were a method name, `this()`. So line 8 is simply calling the constructor on line 3, passing it a randomly selected String rather than a client-code chosen name.

- **Line 11** Notice that the `makeRandomName()` method is marked `static`! That's because you cannot invoke an instance (in other words, nonstatic) method (or access an instance variable) until after the super constructor has run. And since the super constructor will be invoked from the constructor on line 3, rather than from the one on line 7, line 8 can use only a static method to generate the name. If we wanted all animals not specifically named by the caller to have the same default name, say, "Fred," then line 8 could have read `this("Fred");` rather than calling a method that returns a string with the randomly chosen name.
- **Line 12** This doesn't have anything to do with constructors, but since we're all here to learn...it generates a random integer between 0 and 4.
- **Line 13** Weird syntax, we know. We're creating a new String object (just a single String instance), but we want the string to be selected randomly from a list. Except we don't have the list, so we need to make it. So in that one line of code we
  1. Declare a String variable, name.
  2. Create a String array (anonymously—we don't assign the array itself to anything).
  3. Retrieve the string at index [x] (x being the random number generated on line 12) of the newly created String array.
  4. Assign the string retrieved from the array to the declared instance variable name. We could have made it much easier to read if we'd just written

```
String[] nameList = {"Fluffy", "Fido", "Rover", "Spike",
                     "Gigi"};
String name = nameList[x];
```

But where's the fun in that? Throwing in unusual syntax (especially for code wholly unrelated to the real question) is in the spirit of the exam. Don't be startled! (OK, be startled, but then just say to yourself, "Whoa" and get on with it.)

- **Line 18** We're invoking the no-arg version of the constructor (causing a random name from the list to be passed to the other constructor).
- **Line 20** We're invoking the overloaded constructor that takes a string representing the name.

The key point to get from this code example is in line 8. Rather than calling super(), we're calling `this()`, and `this()` always means a call to another constructor in the same class. OK, fine, but what happens after the call to `this()`? Sooner or later the `super()` constructor gets called, right? Yes indeed. A call to `this()` just means you're delaying the inevitable. Some constructor, somewhere, must make the call to `super()`.

Key Rule: The first line in a constructor must be a call to super() or a call to this().

No exceptions. If you have neither of those calls in your constructor, the compiler will insert the no-arg call to `super()`. In other words, if constructor A() has a call to `this()`, the compiler knows that constructor A() will not be the one to invoke `super()`.

The preceding rule means a constructor can never have both a call to `super()` and a call to `this()`. Because each of those calls must be the first statement in a constructor, you can't legally use both in the same constructor. That also means the compiler will not put a call to `super()` in any constructor that has a call to `this()`.

Thought question: What do you think will happen if you try to compile the following code?

```
class A {
   A() {
     this("foo");
   }
   A(String s) {
      this();
   }
}
```

Your compiler may not actually catch the problem (it varies depending on your compiler, but most won't catch the problem). It assumes you know what you're doing. Can you spot the flaw? Given that a super constructor must always be called, where would the call to super() go? Remember, the compiler won't put in a default constructor if you've already got one or more constructors in your class. And when the compiler doesn't put in a default constructor, it still inserts a call to super() in any constructor that doesn't explicitly have a call to the super constructor—unless, that is, the constructor already has a call to this(). So in the preceding code, where can super() go? The only two constructors in the class both have calls to this(), and in fact you'll get exactly what you'd get if you typed the following method code:

```
public void go() {
   doStuff();
}

public void doStuff() {
   go();
}
```

Now can you see the problem? Of course you can. The stack explodes! It gets higher and higher and higher until it just bursts open and method code goes spilling out, oozing out of the JVM right onto the floor. Two overloaded constructors both calling this() are two constructors calling each other. Over and over and over, resulting in

```
% java A
Exception in thread "main" java.lang.StackOverflowError
```

The benefit of having overloaded constructors is that you offer flexible ways to instantiate objects from your class. The benefit of having one constructor invoke another overloaded constructor is to avoid code duplication. In the Animal example, there wasn't any code other than setting the name, but imagine if after line 4 there was still more work to be done in the constructor. By putting all the other constructor work in just one constructor, and then having the other constructors invoke it, you don't have to write and maintain multiple versions of that other important constructor code. Basically, each of the other not-the-real-one overloaded constructors will call another overloaded constructor, passing it whatever data it needs (data the client code didn't supply).

Constructors and instantiation become even more exciting (just when you thought it was safe), when you get to inner classes, but we know you can stand to have only so much fun in one chapter, so we're holding the rest of the discussion on instantiating inner classes until Chapter 8.

CERTIFICATION OBJECTIVE

Statics (Exam Objective 1.3)

1.3 Develop code that declares, initializes, and uses primitives, arrays, enums, and objects as static, instance, and local variables. Also, use legal identifiers for variable names.

Static Variables and Methods

The `static` modifier has such a profound impact on the behavior of a method or variable that we're treating it as a concept entirely separate from the other modifiers. To understand the way a `static` member works, we'll look first at a reason for using one. Imagine you've got a utility class with a method that always runs the same way; its sole function is to return, say, a random number. It wouldn't matter which instance of the class performed the method—it would always behave exactly the same way. In other words, the method's behavior has no dependency on the state (instance variable values) of an object. So why, then, do you need an object when the method will never be instance-specific? Why not just ask the class itself to run the method?

Let's imagine another scenario: Suppose you want to keep a running count of all instances instantiated from a particular class. Where do you actually keep that variable? It won't work to keep it as an instance variable within the class whose instances you're tracking, because the count will just be initialized back to a default value with each new instance. The answer to both the utility-method-always-runs-the-same scenario and the keep-a-running-total-of-instances scenario is to use the `static` modifier. Variables and methods marked `static` belong to the class, rather than to any particular instance. In fact, you can use a `static` method or variable without having any instances of that class at all. You need only have the class available to be able to invoke a `static` method or access a `static` variable. `static` variables, too, can be accessed without having an instance of a class. But if there are instances, a `static` variable of a class will be shared by all instances of that class; there is only one copy.

The following code declares and uses a `static` counter variable:

```
class Frog {
   static int frogCount = 0;  // Declare and initialize
                              // static variable
   public Frog() {
      frogCount += 1;  // Modify the value in the constructor
   }
   public static void main (String [] args) {
      new Frog();
      new Frog();
      new Frog();
      System.out.println("Frog count is now " + frogCount);
   }
}
```

In the preceding code, the static frogCount variable is set to zero when the Frog class is first loaded by the JVM, before any Frog instances are created! (By the way, you don't actually need to initialize a static variable to zero; static variables get the same default values instance variables get.) Whenever a Frog instance is created, the Frog constructor runs and increments the static `frogCount` variable. When this code executes, three Frog instances are created in `main()`, and the result is

```
Frog count is now 3
```

Now imagine what would happen if frogCount were an instance variable (in other words, nonstatic):

```
class Frog {
   int frogCount = 0;  // Declare and initialize
                       // instance variable
   public Frog() {
      frogCount += 1;  // Modify the value in the constructor
   }
   public static void main (String [] args) {
      new Frog();
      new Frog();
      new Frog();
      System.out.println("Frog count is now " + frogCount);
   }
}
```

When this code executes, it should still create three Frog instances in `main()`, but the result is...a compiler error! We can't get this code to compile, let alone run.

```
Frog.java:11: nonstatic variable frogCount cannot be referenced
from a static context
    System.out.println("Frog count is " + frogCount);
                                          ^
    1 error
```

The JVM doesn't know which Frog object's frogCount you're trying to access. The problem is that `main()` is itself a `static` method, and thus isn't running against any particular instance of the class, rather just on the class itself. A `static` method can't access a nonstatic (instance) variable, because there is no instance! That's not to say there aren't instances of the class alive on the heap, but rather that even if there are, the `static` method doesn't know anything about them. The same applies to instance methods; a `static` method can't directly invoke a nonstatic method. Think static = class, nonstatic = instance. Making the method called by the JVM (`main()`) a `static` method means the JVM doesn't have to create an instance of your class just to start running code.

exam watch

One of the mistakes most often made by new Java programmers is attempting to access an instance variable (which means nonstatic variable) from the static `main()` ***method (which doesn't know anything about any instances, so it can't access the variable). The following code is an example of illegal access of a nonstatic variable from a static method:***

```
class Foo {
    int x = 3;
    public static void main (String [] args) {
       System.out.println("x is " + x);
    }
}
```

Understand that this code will never compile, because you can't access a nonstatic (instance) variable from a static method. Just think of the compiler saying, "Hey, I have no idea which Foo object's x variable you're trying to print!" Remember, it's the class running the `main()` ***method, not an instance of the class.***

exam watch

(continued) ***Of course, the tricky part for the exam is that the question won't look as obvious as the preceding code. The problem you're being tested for—accessing a nonstatic variable from a static method—will be buried in code that might appear to be testing something else. For example, the preceding code would be more likely to appear as***

```
class Foo {
    int x = 3;
    float y = 4.3f;
    public static void main (String [] args) {
       for (int z = x; z < ++x; z--, y = y + z)
          // complicated looping and branching code
    }
}
```

So while you're trying to follow the logic, the real issue is that x and y can't be used within `main()`***, because x and y are instance, not static, variables! The same applies for accessing nonstatic methods from a static method. The rule is, a static method of a class can't access a nonstatic (instance) method or variable of its own class.***

Accessing Static Methods and Variables

Since you don't need to have an instance in order to invoke a static method or access a static variable, then how do you invoke or use a static member? What's the syntax? We know that with a regular old instance method, you use the dot operator on a reference to an instance:

```
class Frog {
   int frogSize = 0;
   public int getFrogSize() {
      return frogSize;
   }
   public Frog(int s) {
      frogSize = s;
   }
   public static void main (String [] args) {
```

```
        Frog f = new Frog(25);
        System.out.println(f.getFrogSize()); // Access instance
                                             // method using f
    }
}
```

In the preceding code, we instantiate a Frog, assign it to the reference variable f, and then use that f reference to invoke a method on the Frog instance we just created. In other words, the `getFrogSize()` method is being invoked on a specific Frog object on the heap.

But this approach (using a reference to an object) isn't appropriate for accessing a `static` method, because there might not be any instances of the class at all! So, the way we access a `static` method (or `static` variable) is to use the dot operator on the class name, as opposed to using it on a reference to an instance, as follows:

```
class Frog {
   static int frogCount = 0;  // Declare and initialize
                              // static variable
   public Frog() {
      frogCount += 1;  // Modify the value in the constructor
   }
}

class TestFrog {
   public static void main (String [] args) {
     new Frog();
     new Frog();
     new Frog();
     System.out.print("frogCount:"+Frog.frogCount); //Access
                                                  // static variable
   }
}
```

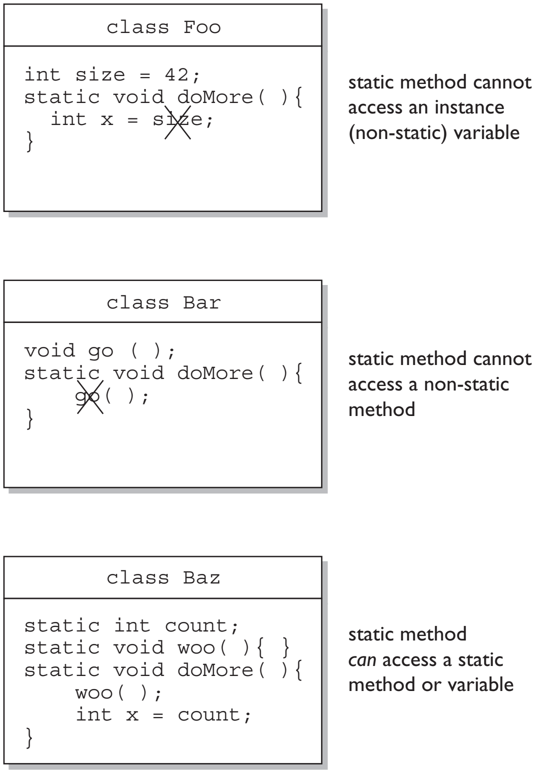
But just to make it really confusing, the Java language also allows you to use an object reference variable to access a static member:

```
Frog f = new Frog();
int frogs = f.frogCount; // Access static variable
                         // FrogCount using f
```

In the preceding code, we instantiate a Frog, assign the new Frog object to the reference variable f, and then use the f reference to invoke a `static` method! But even though we are using a specific Frog instance to access the `static` method, the rules haven't changed. This is merely a syntax trick to let you use an object reference variable (but not the object it refers to) to get to a `static` method or variable, but the `static` member is still unaware of the particular instance used to invoke the `static` member. In the Frog example, the compiler knows that the reference variable f is of type Frog, and so the Frog class `static` method is run with no awareness or concern for the Frog instance at the other end of the f reference. In other words, the compiler cares only that reference variable f is declared as type Frog. Figure 2-8 illustrates the effects of the static modifier on methods and variables.

FIGURE 2-8

The effects of static on methods and variables



Finally, remember that *static methods can't be overridden*! This doesn't mean they can't be redefined in a subclass, but redefining and overriding aren't the same thing. Let's take a look at an example of a redefined (remember, not overridden), `static` method:

```
class Animal {
  static void doStuff() {
    System.out.print("a ");
  }
}
class Dog extends Animal {
  static void doStuff() {         // it's a redefinition,
                                  // not an override
    System.out.print("d ");
  }
  public static void main(String [] args) {
    Animal [] a = {new Animal(), new Dog(), new Animal()};
    for(int x = 0; x < a.length; x++)
      a[x].doStuff();               // invoke the static method
  }
}
```

Running this code produces the output:

```
a a a
```

Remember, the syntax `a[x].doStuff()` is just a shortcut (the syntax trick)…the compiler is going to substitute something like `Animal.doStuff()` instead. Notice that we didn't use the Java 1.5 *enhanced* `for` *loop* here (covered in Chapter 5), even though we could have. Expect to see a mix of both Java 1.4 and Java 5 coding styles and practices on the exam.

CERTIFICATION OBJECTIVE

Coupling and Cohesion (Exam Objective 5.1)

5.1 Develop code that implements tight encapsulation, loose coupling, and high cohesion in classes, and describe the benefits.

We're going to admit it up front. The Sun exam's definitions for cohesion and coupling are somewhat subjective, so what we discuss in this chapter is from the perspective of the exam, and by no means The One True Word on these two OO design principles. It may not be exactly the way that you've learned it, but it's what you need to understand to answer the questions. You'll have very few questions about coupling and cohesion on the real exam.

These two topics, coupling and cohesion, have to do with the quality of an OO design. In general, good OO design calls for *loose coupling* and shuns tight coupling, and good OO design calls for *high cohesion*, and shuns low cohesion. As with most OO design discussions, the goals for an application are

- Ease of creation
- Ease of maintenance
- Ease of enhancement

Coupling

Let's start by making an attempt at a definition of coupling. Coupling is the degree to which one class knows about another class. If the only knowledge that class A has about class B, is what class B has exposed through its interface, then class A and class B are said to be loosely coupled…that's a good thing. If, on the other hand, class A relies on parts of class B that are not part of class B's interface, then the coupling between the classes is tighter…*not* a good thing. In other words, if A knows more than it should about the way in which B was implemented, then A and B are tightly coupled.

Using this second scenario, imagine what happens when class B is enhanced. It's quite possible that the developer enhancing class B has no knowledge of class A, why would she? Class B's developer ought to feel that any enhancements that don't break the class's interface should be safe, so she might change some noninterface part of the class, which then causes class A to break.

At the far end of the coupling spectrum is the horrible situation in which class A knows non-API stuff about class B, and class B knows non-API stuff about class A… this is REALLY BAD. If either class is ever changed, there's a chance that the other class will break. Let's look at an obvious example of tight coupling, which has been enabled by poor encapsulation:

```
class DoTaxes {
  float rate;
```

```
    float doColorado() {
      SalesTaxRates str = new SalesTaxRates();
      rate = str.salesRate;      // ouch
                                 // this should be a method call:
                                 // rate = str.getSalesRate("CO");
      // do stuff with rate
    }
  }

  class SalesTaxRates {
    public float salesRate;            // should be private
    public float adjustedSalesRate;    // should be private

    public float getSalesRate(String region) {
      salesRate = new DoTaxes().doColorado();    // ouch again!
      // do region-based calculations
      return adjustedSalesRate;
    }
  }
```

All nontrivial OO applications are a mix of many classes and interfaces working together. Ideally, all interactions between objects in an OO system should use the APIs, in other words, the contracts, of the objects' respective classes. Theoretically, if all of the classes in an application have well-designed APIs, then it should be possible for all interclass interactions to use those APIs exclusively. As we discussed earlier in this chapter, an aspect of good class and API design is that classes should be well encapsulated.

The bottom line is that coupling is a somewhat subjective concept. Because of this, the exam will test you on really obvious examples of tight coupling; you won't be asked to make subtle judgment calls.

Cohesion

While coupling has to do with how classes interact with each other, cohesion is all about how a single class is designed. The term *cohesion* is used to indicate the degree to which a class has a single, well-focused purpose. Keep in mind that cohesion is a subjective concept. The more focused a class is, the higher its cohesiveness—a good thing. The key benefit of high cohesion is that such classes are typically much easier to maintain (and less frequently changed) than classes with low cohesion. Another benefit of high cohesion is that classes with a well-focused purpose tend to be more reusable than other classes. Let's take a look at a pseudo-code example:

```
class BudgetReport {
  void connectToRDBMS(){ }
  void generateBudgetReport() { }
  void saveToFile() { }
  void print() { }
}
```

Now imagine your manager comes along and says, "Hey you know that accounting application we're working on? The clients just decided that they're also going to want to generate a revenue projection report, oh and they want to do some inventory reporting also. They do like our reporting features however, so make sure that all of these reports will let them choose a database, choose a printer, and save generated reports to data files..." Ouch!

Rather than putting all the printing code into one report class, we probably would have been better off with the following design right from the start:

```
class BudgetReport {
  Options getReportingOptions() { }
  void generateBudgetReport(Options o) { }
}

class ConnectToRDBMS {
  DBconnection getRDBMS() { }
}

class PrintStuff {
  PrintOptions getPrintOptions() { }
}

class FileSaver {
  SaveOptions getFileSaveOptions() { }
}
```

This design is much more cohesive. Instead of one class that does everything, we've broken the system into four main classes, each with a very specific, or *cohesive*, role. Because we've built these specialized, reusable classes, it'll be much easier to write a new report, since we've already got the database connection class, the printing class, and the file saver class, and that means they can be reused by other classes that might want to print a report.

CERTIFICATION SUMMARY

We started the chapter by discussing the importance of encapsulation in good OO design, and then we talked about how good encapsulation is implemented: with private instance variables and public getters and setters.

Next, we covered the importance of inheritance; so that you can grasp overriding, overloading, polymorphism, reference casting, return types, and constructors.

We covered IS-A and HAS-A. IS-A is implemented using inheritance, and HAS-A is implemented by using instance variables that refer to other objects.

Polymorphism was next. Although a reference variable's type can't be changed, it can be used to refer to an object whose type is a subtype of its own. We learned how to determine what methods are invocable for a given reference variable.

We looked at the difference between overridden and overloaded methods, learning that an overridden method occurs when a subclass inherits a method from a superclass, and then reimplements the method to add more specialized behavior. We learned that, at runtime, the JVM will invoke the subclass version on an instance of a subclass, and the superclass version on an instance of the superclass. Abstract methods must be "overridden" (technically, abstract methods must be implemented, as opposed to overridden, since there really isn't anything to override.

We saw that overriding methods must declare the same argument list and return type (or, as of Java 5, they can return a subtype of the declared return type of the superclass overridden method), and that the access modifier can't be more restrictive. The overriding method also can't throw any new or broader checked exceptions that weren't declared in the overridden method. You also learned that the overridden method can be invoked using the syntax `super.doSomething();`.

Overloaded methods let you reuse the same method name in a class, but with different arguments (and, optionally, a different return type). Whereas overriding methods must not change the argument list, overloaded methods must. But unlike overriding methods, overloaded methods are free to vary the return type, access modifier, and declared exceptions any way they like.

We learned the mechanics of casting (mostly downcasting), reference variables, when it's necessary, and how to use the `instanceof` operator.

Implementing interfaces came next. An interface describes a *contract* that the implementing class must follow. The rules for implementing an interface are similar to those for extending an abstract class. Also remember that a class can implement more than one interface, and that interfaces can extend another interface.

We also looked at method return types, and saw that you can declare any return type you like (assuming you have access to a class for an object reference return type), unless you're overriding a method. Barring a covariant return, an overriding method must have the same return type as the overridden method of the superclass. We saw that while overriding methods must not change the return type, overloaded methods can (as long as they also change the argument list).

Finally, you learned that it is legal to return any value or variable that can be implicitly converted to the declared return type. So, for example, a `short` can be returned when the return type is declared as an `int`. And (assuming Horse extends Animal), a Horse reference can be returned when the return type is declared an Animal.

We covered constructors in detail, learning that if you don't provide a constructor for your class, the compiler will insert one. The compiler-generated constructor is called the default constructor, and it is always a no-arg constructor with a no-arg call to super(). The default constructor will never be generated if there is even a single constructor in your class (regardless of the arguments of that constructor), so if you need more than one constructor in your class and you want a no-arg constructor, you'll have to write it yourself. We also saw that constructors are not inherited, and that you can be confused by a method that has the same name as the class (which is legal). The return type is the giveaway that a method is not a constructor, since constructors do not have return types.

We saw how all of the constructors in an object's inheritance tree will always be invoked when the object is instantiated using `new`. We also saw that constructors can be overloaded, which means defining constructors with different argument lists. A constructor can invoke another constructor of the same class using the keyword `this()`, as though the constructor were a method named `this()`. We saw that every constructor must have either `this()` or `super()` as the first statement (although the compiler can insert it for you).

We looked at `static` methods and variables. Static members are tied to the class, not an instance, so there is only one copy of any `static` member. A common mistake is to attempt to reference an instance variable from a `static` method. Use the class name with the dot operator to access `static` members.

We discussed the OO concepts of coupling and cohesion. Loose coupling is the desirable state of two or more classes that interact with each other only through their respective API's. Tight coupling is the undesirable state of two or more classes that know inside details about another class, details not revealed in the class's API. High cohesion is the desirable state of a single class whose purpose and responsibilities are limited and well-focused.

And once again, you learned that the exam includes tricky questions designed largely to test your ability to recognize just how tricky the questions can be.

✓ TWO-MINUTE DRILL

Here are some of the key points from each certification objective in this chapter.

Encapsulation, IS-A, HAS-A (Objective 5.1)

- ❑ Encapsulation helps hide implementation behind an interface (or API).
- ❑ Encapsulated code has two features:
  - ❑ Instance variables are kept protected (usually with the private modifier).
  - ❑ Getter and setter methods provide access to instance variables.
- ❑ IS-A refers to inheritance or implementation.
- ❑ IS-A is expressed with the keyword `extends`.
- ❑ IS-A, "inherits from," and "is a subtype of " are all equivalent expressions.
- ❑ HAS-A means an instance of one class "has a" reference to an instance of another class or another instance of the same class.

Inheritance (Objective 5.5)

- ❑ Inheritance allows a class to be a subclass of a superclass, and thereby inherit `public` and `protected` variables and methods of the superclass.
- ❑ Inheritance is a key concept that underlies IS-A, polymorphism, overriding, overloading, and casting.
- ❑ All classes (except class `Object`), are subclasses of type `Object`, and therefore they inherit `Object`'s methods.

Polymorphism (Objective 5.2)

- ❑ Polymorphism means "many forms."
- ❑ A reference variable is always of a single, unchangeable type, but it can refer to a subtype object.
- ❑ A single object can be referred to by reference variables of many different types—as long as they are the same type or a supertype of the object.
- ❑ The reference variable's type (not the object's type), determines which methods can be called!
- ❑ Polymorphic method invocations apply only to overridden *instance* methods.

Overriding and Overloading (Objectives 1.5 and 5.4)

- ❑ Methods can be overridden or overloaded; constructors can be overloaded but not overridden.
- ❑ Abstract methods must be overridden by the first concrete (non-abstract) subclass.
- ❑ With respect to the method it overrides, the overriding method
  - ❑ Must have the same argument list.
  - ❑ Must have the same return type, except that as of Java 5, the return type can be a subclass—this is known as a covariant return.
  - ❑ Must not have a more restrictive access modifier.
  - ❑ May have a less restrictive access modifier.
  - ❑ Must not throw new or broader checked exceptions.
  - ❑ May throw fewer or narrower checked exceptions, or any unchecked exception.
- ❑ `final` methods cannot be overridden.
- ❑ Only inherited methods may be overridden, and remember that private methods are not inherited.
- ❑ A subclass uses `super.overriddenMethodName()` to call the superclass version of an overridden method.
- ❑ Overloading means reusing a method name, but with different arguments.
- ❑ Overloaded methods
  - ❑ Must have different argument lists
  - ❑ May have different return types, if argument lists are also different
  - ❑ May have different access modifiers
  - ❑ May throw different exceptions
- ❑ Methods from a superclass can be overloaded in a subclass.
- ❑ Polymorphism applies to overriding, not to overloading.
- ❑ Object type (not the reference variable's type), determines which overridden method is used at runtime.
- ❑ Reference type determines which overloaded method will be used at compile time.

Reference Variable Casting (Objective 5.2)

- There are two types of reference variable casting: downcasting and upcasting.
- Downcasting: If you have a reference variable that refers to a subtype object, you can assign it to a reference variable of the subtype. You must make an explicit cast to do this, and the result is that you can access the subtype's members with this new reference variable.
- Upcasting: You can assign a reference variable to a supertype reference variable explicitly or implicitly. This is an inherently safe operation because the assignment restricts the access capabilities of the new variable.

Implementing an Interface (Objective 1.2)

- When you implement an interface, you are fulfilling its contract.
- You implement an interface by properly and concretely overriding all of the methods defined by the interface.
- A single class can implement many interfaces.

Return Types (Objective 1.5)

- Overloaded methods can change return types; overridden methods cannot, except in the case of covariant returns.
- Object reference return types can accept `null` as a return value.
- An array is a legal return type, both to declare and return as a value.
- For methods with primitive return types, any value that can be implicitly converted to the return type can be returned.
- Nothing can be returned from a `void`, but you can return nothing. You're allowed to simply say `return`, in any method with a `void` return type, to bust out of a method early. But you can't return nothing from a method with a non-void return type.
- Methods with an object reference return type, can return a subtype.
- Methods with an interface return type, can return any implementer.

Constructors and Instantiation (Objectives 1.6 and 5.4)

- A constructor is always invoked when a new object is created.

- Each superclass in an object's inheritance tree will have a constructor called.
- Every class, even an abstract class, has at least one constructor.
- Constructors must have the same name as the class.
- Constructors don't have a return type. If you see code with a return type, it's a method with the same name as the class, it's not a constructor.
- Typical constructor execution occurs as follows:
  - The constructor calls its superclass constructor, which calls its superclass constructor, and so on all the way up to the Object constructor.
  - The Object constructor executes and then returns to the calling constructor, which runs to completion and then returns to its calling constructor, and so on back down to the completion of the constructor of the actual instance being created.
- Constructors can use any access modifier (even `private`!).
- The compiler will create a default constructor if you don't create any constructors in your class.
- The default constructor is a no-arg constructor with a no-arg call to `super()`.
- The first statement of every constructor must be a call to either `this()` (an overloaded constructor) or `super()`.
- The compiler will add a call to `super()` unless you have already put in a call to `this()` or `super()`.
- Instance members are accessible only after the super constructor runs.
- Abstract classes have constructors that are called when a concrete subclass is instantiated.
- Interfaces do not have constructors.
- If your superclass does not have a no-arg constructor, you must create a constructor and insert a call to `super()` with arguments matching those of the superclass constructor.
- Constructors are never inherited, thus they cannot be overridden.
- A constructor can be directly invoked only by another constructor (using a call to `super()` or `this()`).
- Issues with calls to `this()`
  - May appear only as the first statement in a constructor.
  - The argument list determines which overloaded constructor is called.

- ❑ Constructors can call constructors can call constructors, and so on, but sooner or later one of them better call `super()` or the stack will explode.
- ❑ Calls to `this()` and `super()` cannot be in the same constructor. You can have one or the other, but never both.

Statics (Objective 1.3)

- ❑ Use `static` methods to implement behaviors that are not affected by the state of any instances.
- ❑ Use `static` variables to hold data that is class specific as opposed to instance specific—there will be only one copy of a `static` variable.
- ❑ All `static` members belong to the class, not to any instance.
- ❑ A `static` method can't access an instance variable directly.
- ❑ Use the dot operator to access `static` members, but remember that using a reference variable with the dot operator is really a syntax trick, and the compiler will substitute the class name for the reference variable, for instance:

```
d.doStuff();
```

  becomes:

```
Dog.doStuff();
```

- ❑ `static` methods can't be overridden, but they can be redefined.

Coupling and Cohesion (Objective 5.1)

- ❑ Coupling refers to the degree to which one class knows about or uses members of another class.
- ❑ Loose coupling is the desirable state of having classes that are well encapsulated, minimize references to each other, and limit the breadth of API usage.
- ❑ Tight coupling is the undesirable state of having classes that break the rules of loose coupling.
- ❑ Cohesion refers to the degree in which a class has a single, well-defined role or responsibility.
- ❑ High cohesion is the desirable state of a class whose members support a single, well-focused role or responsibility.
- ❑ Low cohesion is the undesirable state of a class whose members support multiple, unfocused roles or responsibilities.

SELF TEST

1. Given:

```
public abstract interface Frobnicate { public void twiddle(String s); }
```

Which is a correct class? (Choose all that apply.)

A.
```
public abstract class Frob implements Frobnicate {
       public abstract void twiddle(String s) { }
     }
```
B.
```
public abstract class Frob implements Frobnicate { }
```
C.
```
public class Frob extends Frobnicate {
       public void twiddle(Integer i) { }
     }
```
D.
```
public class Frob implements Frobnicate {
       public void twiddle(Integer i) { }
     }
```
E.
```
public class Frob implements Frobnicate {
       public void twiddle(String i) { }
       public void twiddle(Integer s) { }
     }
```

2. Given:

```
class Top {
  public Top(String s) { System.out.print("B"); }
}
public class Bottom2 extends Top {
  public Bottom2(String s) { System.out.print("D"); }
  public static void main(String [] args) {
    new Bottom2("C");
    System.out.println(" ");
  }
}
```

What is the result?

A. BD

B. DB

C. BDC

D. DBC

E. Compilation fails

3. Given:

```
class Clidder {
  private final void flipper() { System.out.println("Clidder"); }
}

public class Clidlet extends Clidder {
  public final void flipper() { System.out.println("Clidlet");  }
  public static void main(String [] args) {
    new Clidlet().flipper();
  }
}
```

What is the result?

A. `Clidlet`

B. `Clidder`

C. `Clidder`
`Clidlet`

D. `Clidlet`
`Clidder`

E. Compilation fails

4. Using the **fragments** below, complete the following **code** so it compiles. Note, you may not have to fill all of the slots.

Code:

```
class AgedP {
  __________ __________ __________ __________ __________
  public AgedP(int x) {
    __________ __________ __________ __________ __________
  }
}
public class Kinder extends AgedP {
  __________ __________ __________ __________ __________ __________
  public Kinder(int x) {
    __________ __________ __________ __________ __________ ();
  }
}
```

Fragments: Use the following fragments zero or more times:

`AgedP`	`super`	`this`	
`(`	`)`	`{`	`}`
`;`			

5. Which statement(s) are true? (Choose all that apply.)
   - A. Cohesion is the OO principle most closely associated with hiding implementation details
   - B. Cohesion is the OO principle most closely associated with making sure that classes know about other classes only through their APIs
   - C. Cohesion is the OO principle most closely associated with making sure that a class is designed with a single, well-focused purpose
   - D. Cohesion is the OO principle most closely associated with allowing a single object to be seen as having many types

6. Given the following,

```
 1. class X { void do1() { } }
 2. class Y extends X { void do2() { } }
 3.
 4. class Chrome {
 5.   public static void main(String [] args) {
 6.     X x1 = new X();
 7.     X x2 = new Y();
 8.     Y y1 = new Y();
 9.     // insert code here
10. } }
```

Which, inserted at line 9, will compile? (Choose all that apply.)

- A. `x2.do2();`
- B. `(Y)x2.do2();`
- C. `((Y)x2).do2();`
- D. None of the above statements will compile

7. Given:

   1. ClassA has a ClassD
   2. Methods in ClassA use public methods in ClassB
   3. Methods in ClassC use public methods in ClassA
   4. Methods in ClassA use public variables in ClassB

   Which is most likely true? (Choose the most likely.)

   A. ClassD has low cohesion
   B. ClassA has weak encapsulation
   C. ClassB has weak encapsulation
   D. ClassB has strong encapsulation
   E. ClassC is tightly coupled to ClassA

8. Given:

```
 3. class Dog {
 4.   public void bark() { System.out.print("woof "); }
 5. }
 6. class Hound extends Dog {
 7.   public void sniff() { System.out.print("sniff "); }
 8.   public void bark() { System.out.print("howl "); }
 9. }
10. public class DogShow {
11.   public static void main(String[] args) { new DogShow().go(); }
12.   void go() {
13.     new Hound().bark();
14.     ((Dog) new Hound()).bark();
15.     ((Dog) new Hound()).sniff();
16.   }
17. }
```

   What is the result? (Choose all that apply.)

   A. `howl howl sniff`
   B. `howl woof sniff`
   C. `howl howl` followed by an exception
   D. `howl woof` followed by an exception
   E. Compilation fails with an error at line 14
   F. Compilation fails with an error at line 15

9. Given:

```
 3. public class Redwood extends Tree {
 4.   public static void main(String[] args) {
 5.     new Redwood().go();
 6.   }
 7.   void go() {
 8.     go2(new Tree(), new Redwood());
 9.     go2((Redwood) new Tree(), new Redwood());
10.   }
11.   void go2(Tree t1, Redwood r1) {
12.      Redwood r2 = (Redwood)t1;
13.      Tree t2 = (Tree)r1;
14.   }
15. }
16. class Tree { }
```

What is the result? (Choose all that apply.)

A. An exception is thrown at runtime

B. The code compiles and runs with no output

C. Compilation fails with an error at line 8

D. Compilation fails with an error at line 9

E. Compilation fails with an error at line 12

F. Compilation fails with an error at line 13

10. Given:

```
public class Tenor extends Singer {
  public static String sing() { return "fa"; }
  public static void main(String[] args) {
    Tenor t = new Tenor();
    Singer s = new Tenor();
    System.out.println(t.sing() + " " + s.sing());
  }
}
class Singer { public static String sing() { return "la"; } }
```

What is the result?

A. `fa fa`

B. `fa la`

C. `la la`

D. Compilation fails

E. An exception is thrown at runtime

11. Given:

```
class Alpha {
  static String s = " ";
  protected Alpha() { s += "alpha "; }
}
class SubAlpha extends Alpha {
  private SubAlpha() { s += "sub "; }
}
public class SubSubAlpha extends Alpha {
  private SubSubAlpha() { s += "subsub "; }
  public static void main(String[] args) {
    new SubSubAlpha();
    System.out.println(s);
  }
}
```

What is the result?

A. `subsub`

B. `sub subsub`

C. `alpha subsub`

D. `alpha sub subsub`

E. Compilation fails

F. An exception is thrown at runtime

12. Given:

```
class Building {
  Building() {  System.out.print("b ");  }
  Building(String name) {
    this();   System.out.print("bn " + name);
  }
}
public class House extends Building {
  House() {  System.out.print("h ");  }
  House(String name) {
    this();   System.out.print("hn " + name);
  }
  public static void main(String[] args) { new House("x "); }
}
```

What is the result?

A. `h hn x`

B. `hn x h`

C. `b h hn x`

D. `b hn x h`

E. `bn x h hn x`

F. `b bn x h hn x`

G. `bn x b h hn x`

H. Compilation fails

13. Given:

```
class Mammal {
  String name = "furry ";
  String makeNoise() { return "generic noise"; }
}
class Zebra extends Mammal {
  String name = "stripes ";
  String makeNoise() { return "bray"; }
}
public class ZooKeeper {
  public static void main(String[] args) { new ZooKeeper().go(); }
  void go() {
    Mammal m = new Zebra();
    System.out.println(m.name + m.makeNoise());
  }
}
```

What is the result?

A. `furry bray`

B. `stripes bray`

C. `furry generic noise`

D. `stripes generic noise`

E. Compilation fails

F. An exception is thrown at runtime

14. You're designing a new online board game in which Floozels are a type of Jammers, Jammers can have Quizels, Quizels are a type of Klakker, and Floozels can have several Floozets. Which of the following fragments represent this design? (Choose all that apply.)

A.
```
import java.util.*;
interface Klakker { }
class Jammer { Set<Quizel> q; }
class Quizel implements Klakker { }
public class Floozel extends Jammer { List<Floozet> f; }
interface Floozet { }
```

B.
```
import java.util.*;
class Klakker { Set<Quizel> q; }
class Quizel extends Klakker { }
class Jammer { List<Floozel> f; }
class Floozet extends Floozel { }
public class Floozel { Set<Klakker> k; }
```

C.
```
import java.util.*;
class Floozet { }
class Quizel implements Klakker { }
class Jammer { List<Quizel> q; }
interface Klakker { }
class Floozel extends Jammer { List<Floozet> f; }
```

D.
```
import java.util.*;
interface Jammer extends Quizel { }
interface Klakker { }
interface Quizel extends Klakker { }
interface Floozel extends Jammer, Floozet { }
interface Floozet { }
```

15. Given:

```
class A { }
class B extends A { }
public class ComingThru {
  static String s = "-";
  public static void main(String[] args) {
    A[] aa = new A[2];
    B[] ba = new B[2];
    sifter(aa);
    sifter(ba);
    sifter(7);
    System.out.println(s);
  }
```

```
    static void sifter(A[]... a2)     { s += "1"; }
    static void sifter(B[]... b1)     { s += "2"; }
    static void sifter(B[] b1)        { s += "3"; }
    static void sifter(Object o)      { s += "4"; }
}
```

What is the result?

A. `-124`

B. `-134`

C. `-424`

D. `-434`

E. `-444`

F. Compilation fails

SELF TEST ANSWERS

1. Given:

```
public abstract interface Frobnicate { public void twiddle(String s); }
```

Which is a correct class? (Choose all that apply.)

A.
```
public abstract class Frob implements Frobnicate {
        public abstract void twiddle(String s) { }
      }
```
B.
```
public abstract class Frob implements Frobnicate { }
```
C.
```
public class Frob extends Frobnicate {
        public void twiddle(Integer i) { }
      }
```
D.
```
public class Frob implements Frobnicate {
        public void twiddle(Integer i) { }
      }
```
E.
```
public class Frob implements Frobnicate {
        public void twiddle(String i) { }
        public void twiddle(Integer s) { }
      }
```

Answer:

☑ **B** is correct, an `abstract` class need not implement any or all of an interface's methods. **E** is correct, the class implements the interface method and additionally overloads the `twiddle()` method.

☒ **A** is incorrect because `abstract` methods have no body. **C** is incorrect because classes implement interfaces they don't extend them. **D** is incorrect because overloading a method is not implementing it.
(Objective 5.4)

2. Given:

```
class Top {
  public Top(String s) { System.out.print("B"); }
}
public class Bottom2 extends Top {
  public Bottom2(String s) { System.out.print("D"); }
  public static void main(String [] args) {
    new Bottom2("C");
    System.out.println(" ");
} }
```

What is the result?

A. `BD`

B. `DB`

C. `BDC`

D. `DBC`

E. Compilation fails

Answer:

☑ **E** is correct. The implied `super()` call in Bottom2's constructor cannot be satisfied because there isn't a no-arg constructor in Top. A default, no-arg constructor is generated by the compiler only if the class has no constructor defined explicitly.

☒ **A, B, C,** and **D** are incorrect based on the above.
(Objective 1.6)

3. Given:

```
class Clidder {
  private final void flipper() { System.out.println("Clidder"); }
}

public class Clidlet extends Clidder {
  public final void flipper() { System.out.println("Clidlet");  }
  public static void main(String [] args) {
    new Clidlet().flipper();
} }
```

What is the result?

A. `Clidlet`

B. `Clidder`

C. `Clidder`
`Clidlet`

D. `Clidlet`
`Clidder`

E. Compilation fails

Answer:

☑ **A** is correct. Although a final method cannot be overridden, in this case, the method is private, and therefore hidden. The effect is that a new, accessible, method flipper is created. Therefore, no polymorphism occurs in this example, the method invoked is simply that of the child class, and no error occurs.

☒ **B, C, D,** and **E** are incorrect based on the preceding.
(Objective 5.3)

4. Using the **fragments** below, complete the following **code** so it compiles. Note, you may not have to fill all of the slots.

Code:

```
class AgedP {
  __________ __________ __________ __________ __________
  public AgedP(int x) {
    __________ __________ __________ __________ __________
  }
}
public class Kinder extends AgedP {
  __________ __________ __________ __________ __________ __________
  public Kinder(int x) {
    __________ __________ __________ __________ __________ ();
  }
}
```

Fragments: Use the following fragments zero or more times:

AgedP	super	this	
(	)	{	}
;			

Answer:

```
class AgedP {
  AgedP() {}
  public AgedP(int x) {
  }
}
public class Kinder extends AgedP {
  public Kinder(int x) {
    super();
  }
}
```

As there is no droppable tile for the variable x and the parentheses (in the Kinder constructor), are already in place and empty, there is no way to construct a call to the superclass constructor

that takes an argument. Therefore, the only remaining possibility is to create a call to the no-argument superclass constructor. This is done as: `super();`. The line cannot be left blank, as the parentheses are already in place. Further, since the superclass constructor called is the no-argument version, this constructor must be created. It will not be created by the compiler because there is another constructor already present.
(Objective 5.4)

5 Which statement(s) are true? (Choose all that apply.)

A. Cohesion is the OO principle most closely associated with hiding implementation details

B. Cohesion is the OO principle most closely associated with making sure that classes know about other classes only through their APIs

C. Cohesion is the OO principle most closely associated with making sure that a class is designed with a single, well-focused purpose

D. Cohesion is the OO principle most closely associated with allowing a single object to be seen as having many types

Answer:

☑ Answer **C** is correct.

☒ **A** refers to encapsulation, **B** refers to coupling, and **D** refers to polymorphism.
(Objective 5.1)

6. Given the following,

```
 1. class X { void do1() { } }
 2. class Y extends X { void do2() { } }
 3.
 4. class Chrome {
 5.   public static void main(String [] args) {
 6.     X x1 = new X();
 7.     X x2 = new Y();
 8.     Y y1 = new Y();
 9.     // insert code here
10.   }
11. }
```

Which, inserted at line 9, will compile? (Choose all that apply.)

A. `x2.do2();`

B. `(Y)x2.do2();`

C. `((Y)x2).do2();`

D. None of the above statements will compile

Answer:

☑ **C** is correct. Before you can invoke `Y`'s `do2` method you have to cast `x2` to be of type `Y`. Statement **B** looks like a proper cast but without the second set of parentheses, the compiler thinks it's an incomplete statement.

☒ **A, B** and **D** are incorrect based on the preceding.
(Objective 5.2)

7. Given:

1. ClassA has a ClassD
2. Methods in ClassA use public methods in ClassB
3. Methods in ClassC use public methods in ClassA
4. Methods in ClassA use public variables in ClassB

Which is most likely true? (Choose the most likely.)

A. ClassD has low cohesion

B. ClassA has weak encapsulation

C. ClassB has weak encapsulation

D. ClassB has strong encapsulation

E. ClassC is tightly coupled to ClassA

Answer:

☑ **C** is correct. Generally speaking, public variables are a sign of weak encapsulation.

☒ **A, B, D,** and **E** are incorrect, because based on the information given, none of these statements can be supported.
(Objective 5.1)

8. Given:

```
3. class Dog {
4.   public void bark() { System.out.print("woof "); }
5. }
6. class Hound extends Dog {
7.   public void sniff() { System.out.print("sniff "); }
```

```
 8.   public void bark() { System.out.print("howl "); }
 9. }
10. public class DogShow {
11.   public static void main(String[] args) { new DogShow().go(); }
12.   void go() {
13.     new Hound().bark();
14.     ((Dog) new Hound()).bark();
15.     ((Dog) new Hound()).sniff();
16.   }
17. }
```

What is the result? (Choose all that apply.)

A. `howl howl sniff`

B. `howl woof sniff`

C. `howl howl` followed by an exception

D. `howl woof` followed by an exception

E. Compilation fails with an error at line 14

F. Compilation fails with an error at line 15

Answer:

☑ **F** is correct. Class `Dog` doesn't have a `sniff` method.

☒ **A, B, C, D,** and **E** are incorrect based on the above information.
(Objective 5.2)

9. Given:

```
public class Redwood extends Tree {
  public static void main(String[] args) {
    new Redwood().go();
  }
  void go() {
    go2(new Tree(), new Redwood());
    go2((Redwood) new Tree(), new Redwood());
  }
  void go2(Tree t1, Redwood r1) {
     Redwood r2 = (Redwood)t1;
     Tree t2 = (Tree)r1;
  }
}
class Tree { }
```

What is the result? (Choose all that apply.)

A. An exception is thrown at runtime

B. The code compiles and runs with no output

C. Compilation fails with an error at line 8

D. Compilation fails with an error at line 9

E. Compilation fails with an error at line 12

F. Compilation fails with an error at line 13

Answer:

☑ **A** is correct, a ClassCastException will be thrown when the code attempts to downcast a Tree to a Redwood.

☒ **B, C, D, E,** and **F** are incorrect based on the above information.
(Objective 5.2)

10. Given:

```
public class Tenor extends Singer {
  public static String sing() { return "fa"; }
  public static void main(String[] args) {
    Tenor t = new Tenor();
    Singer s = new Tenor();
    System.out.println(t.sing() + " " + s.sing());
  }
}
class Singer { public static String sing() { return "la"; } }
```

What is the result?

A. `fa fa`

B. `fa la`

C. `la la`

D. Compilation fails

E. An exception is thrown at runtime

Answer:

☑ **B** is correct. The code is correct, but polymorphism doesn't apply to static methods.

☒ **A, C, D,** and **E** are incorrect based on the above information.
(Objective 5.2)

11. Given:

```
class Alpha {
  static String s = " ";
  protected Alpha() { s += "alpha "; }
}
class SubAlpha extends Alpha {
  private SubAlpha() { s += "sub "; }
}
public class SubSubAlpha extends Alpha {
  private SubSubAlpha() { s += "subsub "; }
  public static void main(String[] args) {
    new SubSubAlpha();
    System.out.println(s);
  }
}
```

What is the result?

A. `subsub`

B. `sub subsub`

C. `alpha subsub`

D. `alpha sub subsub`

E. Compilation fails

F. An exception is thrown at runtime

Answer:

☑ **C** is correct. Watch out, `SubSubAlpha` extends `Alpha`! Since the code doesn't attempt to make a `SubAlpha`, the private constructor in `SubAlpha` is okay.

☒ **A, B, D, E,** and **F** are incorrect based on the above information. (Objective 5.3)

12. Given:

```
class Building {
  Building() {  System.out.print("b ");  }
  Building(String name) {
    this();   System.out.print("bn " + name);
  }
}
public class House extends Building {
```

```
  House() {  System.out.print("h ");  }
  House(String name) {
    this();   System.out.print("hn " + name);
  }
  public static void main(String[] args) { new House("x "); }
}
```

What is the result?

A. `h hn x`

B. `hn x h`

C. `b h hn x`

D. `b hn x h`

E. `bn x h hn x`

F. `b bn x h hn x`

G. `bn x b h hn x`

H. Compilation fails

Answer:

☑ **C** is correct. Remember that constructors call their superclass constructors, which execute first, and that constructors can be overloaded.

☒ **A, B, D, E, F, G,** and **H** are incorrect based on the above information. (Objectives 1.6, 5.4)

13. Given:

```
class Mammal {
  String name = "furry ";
  String makeNoise() { return "generic noise"; }
}
class Zebra extends Mammal {
  String name = "stripes ";
  String makeNoise() { return "bray"; }
}
public class ZooKeeper {
  public static void main(String[] args) { new ZooKeeper().go(); }
  void go() {
    Mammal m = new Zebra();
    System.out.println(m.name + m.makeNoise());
  }
}
```

What is the result?

A. `furry bray`

B. `stripes bray`

C. `furry generic noise`

D. `stripes generic noise`

E. Compilation fails

F. An exception is thrown at runtime

Answer:

☑ **A** is correct. Polymorphism is only for instance methods.

☒ **B, C, D, E,** and **F** are incorrect based on the above information.
(Objectives 1.5, 5.4)

14. You're designing a new online board game in which Floozels are a type of Jammers, Jammers can have Quizels, Quizels are a type of Klakker, and Floozels can have several Floozets. Which of the following fragments represent this design? (Choose all that apply.)

A.
```
import java.util.*;
interface Klakker { }
class Jammer { Set<Quizel> q; }
class Quizel implements Klakker { }
public class Floozel extends Jammer { List<Floozet> f; }
interface Floozet { }
```

B.
```
import java.util.*;
class Klakker { Set<Quizel> q; }
class Quizel extends Klakker { }
class Jammer { List<Floozel> f; }
class Floozet extends Floozel { }
public class Floozel { Set<Klakker> k; }
```

C.
```
import java.util.*;
class Floozet { }
class Quizel implements Klakker { }
class Jammer { List<Quizel> q; }
interface Klakker { }
class Floozel extends Jammer { List<Floozet> f; }
```

D.
```
import java.util.*;
interface Jammer extends Quizel { }
interface Klakker { }
interface Quizel extends Klakker { }
interface Floozel extends Jammer, Floozet { }
interface Floozet { }
```

Answer:

☑ **A** and **C** are correct. The phrase "type of" indicates an "is-a" relationship (extends or implements), and the phrase "have" is of course a "has-a" relationship (usually instance variables).

☒ **B** and **D** are incorrect based on the above information.
(Objective 5.5)

15. Given:

```
class A { }
class B extends A { }
public class ComingThru {
  static String s = "-";
  public static void main(String[] args) {
    A[] aa = new A[2];
    B[] ba = new B[2];
    sifter(aa);
    sifter(ba);
    sifter(7);
    System.out.println(s);
  }
  static void sifter(A[]... a2)    { s += "1"; }
  static void sifter(B[]... b1)    { s += "2"; }
  static void sifter(B[] b1)       { s += "3"; }
  static void sifter(Object o)     { s += "4"; }
}
```

What is the result?

A. `-124`

B. `-134`

C. `-424`

D. `-434`

E. `-444`

F. Compilation fails

Answer:

☑ **D** is correct. In general, overloaded var-args methods are chosen last. Remember that arrays are objects. Finally, an int can be boxed to an Integer and then "widened" to an Object.

☒ **A, B, C, E,** and **F** are incorrect based on the above information.
(Objective 1.5)