The `static` Keyword and Inheritance

Today, we look at when and how to use the `static` keyword in Java. We then examine ***inheritance***, one of the pillars of object-oriented design.

Content Learning Targets

After completing this activity, you should be able to say:

- I can differentiate between static and instance variables and methods.
- I can summarize best practices for when to use static variables and methods.
- I can explain what it means for one class to extend another and summarize the `extends` and `super` keywords.
- I can generalize multiple classes that have overlapping code.
- I can explain the requirements of abstract classes and methods.
- I can write a new method for an existing Java library class.

Process Skill Goals

During the activity, you should make progress toward:

- Reading Java API documentation and making inferences. (Information Processing)
- Making conclusions based on IDE hints and program output. (Critical Thinking)

Facilitation Notes

First Hour: Model 1 introduces static fields and methods through examples. Be sure to summarize best practices at the end: only use static fields for constants (until later courses), and only use static methods for utility functions and `main`.

End the first hour with a 10-minute mini lecture that shows how to create and add two BigIntegers, and how to find and replace strings.

Second Hour: Model 2 introduces inheritance with a custom extension of `BigInteger`. This activity requires some prior knowledge of BigInteger and the `String.replace()` method. BigInteger was originally chosen for this activity, because (1) it's a useful class in the Java library, and (2) it's not declared as `final` (so it can be extended). The new feature this activity is adding to BigInteger is the ability to work with comma separators. Mention that BigInteger extends Number, which extends Object. Notice the static constants. Prevent students from spending too much time on #13 and #14.

Model 3 introduces abstract superclasses.

Key questions: #4, #12, #15, #17, #23, #34

Source files: *Point.java*, *MyBigInt.java*, *LoudToy.java*, *ToySheep.java*, *ToyRobot.java*, *StudentV1[/V2].java*

Model 1 The `static` Keyword

We have seen the `static` Java keyword come up in a few situations. It's time for a deep dive into what it means and how to use it.

Version 1:

```
public class StudentV1 {
    private String name;
    private char grade;

    public StudentV1(String name, char grd) {
        this.name = name;
        this.grade = grd;
    }

    @Override
    public String toString() {
        return name + " earned " + grade;
    }

    public static void main(String[] args) {
        StudentV1 a =
            new StudentV1("Adaline", 'A');
        StudentV1 b =
            new StudentV1("Belicia", 'B');
        StudentV1 c =
            new StudentV1("Charlie", 'C');
        System.out.println(a);
        System.out.println(b);
        System.out.println(c);
    }
}
```

Version 2:

```
public class StudentV2 {
    private String name;
    private static char grade;

    public StudentV2(String name, char grd) {
        this.name = name;
        StudentV2.grade = grd;
    }

    @Override
    public String toString() {
        return name + " earned " + grade;
    }

    public static void main(String[] args) {
        StudentV2 a =
            new StudentV2("Adaline", 'A');
        StudentV2 b =
            new StudentV2("Belicia", 'B');
        StudentV2 c =
            new StudentV2("Charlie", 'C');
        System.out.println(a);
        System.out.println(b);
        System.out.println(c);
    }
}
```

Questions (20 min) Start time:

1. Examine the two versions of a simple `Student` class above. Notice the subtle differences, and predict the output of each. ***After*** predicting, run them (in `src/student`) to confirm.

`StudentV1` output:

```
Adaline earned A
Belicia earned B
Charlie earned C
```

`StudentV2` output:

```
Adaline earned C
Belicia earned C
Charlie earned C
```

2. The English word ***static*** can take several different meanings. Based on this example, which meaning do you think Java is using?

"showing little change" fits best (or "stationary"); in V2, the static variable `grade` is shared between all `StudentV2` instances. Its value is tied to the ***class***, not individual instances.

3. In the Java API docs for the `Integer` class, find the list of fields. What are some of the `static` fields in this class? Click on each field's name to see more info.

`BYTES`, `MAX_VALUE`, `MIN_VALUE`, `SIZE`, `TYPE`. Note all are declared as `public static final`, where the `final` keyword means their values cannot change once initialized.

4. Look at `static` fields in other Java classes, such as `Math`, `Calendar`, and `HttpURLConnection`. Based on what you find, what do you think are some patterns/conventions/best practices for using `static` fields?

Notable examples: `Math.PI`, `HttpURLConnection.HTTP_NOT_FOUND`, and `Calendar.SUNDAY` (and `MONDAY`, etc.). Patterns: (1) Accessed by the syntax `ClassName.FIELD_NAME`. (2) Usually named with all-caps and underscores. (3) Often used to give constants descriptive names.

Methods can also be declared as `static`, meaning they are associated with the class itself and not with individual instances. In fact, we can call static methods (a.k.a. class methods) without ever creating an instance of the object type. A static method has ***unchanging*** behavior: it is not state-dependent, meaning it does not do different things depending on the data stored in the current object instance. Static methods are (almost always) true functions, in the mathematical sense: for each valid input, they will give the same output every time.

5. We have already used one static method in the `Integer` class: `Integer.parseInt(String s)`. (Notice the camel-case naming convention and the `ClassName.methodName()` syntax.) Look at the list of `static` methods in `Integer`. What are some typical use cases for static methods?

comparing two `int` values or finding their max/min, counting leading/trailing zeros, converting from one numerical representation to another, manipulating the binary, etc.

6. We always declare the `main` method in Java as `static`. Why do you think this is necessary?

If `main` was not `static`, we would have to instantiate an object to call it. But we can't run any code (let alone instantiate an object) until we start the program by running `main`, so we would get a chicken-and-egg problem: which came first, the instance or the `main` call? Java ***could*** have been designed to start by instantiating an object of the main class type and ***then*** calling main, but this can get messy.

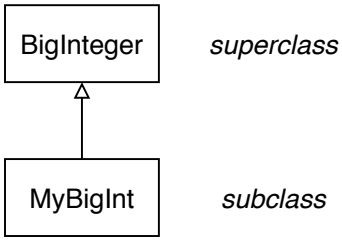
7. Examine the provided ***Point.java*** file. Uncomment the print statements, and add the missing methods. Which one is static? How do the two distance methods differ in "point" of view?

The static method is `distanceBetween`. It represents a "completely objective third-party observer with absolutely no personal interest in the matter" that's looking at `a` and `b` and measuring the distance in between. The non-static (instance) method is `distanceTo`. It represents a "first-person" perspective: Point `a` looks at point `b` and measures how far away it is.

Model 2 Extending Classes: My Big Integer

The following class extends the functionality of `BigInteger` to allow comma-separated strings (e.g., `"123,465,789"`). The UML diagram summarizes the relationship between the two classes.

```
1  import java.math.BigInteger;
2
3  public class MyBigInt extends BigInteger {
4
5      public MyBigInt(String val) {
6          // remove comma characters
7          super(val.replace(",",  ""));
8      }
9
10     public String toString() {
11         // start with the decimal representation
12         String str = super.toString();
13         StringBuilder sb = new StringBuilder(str);
14
15         // insert comma separators every three digits
16         for (int i = sb.length() - 3; i > 0; i -= 3) {
17             sb.insert(i, ',');
18         }
19         return sb.toString();
20     }
21
22 }
```



Questions (20 min) Start time:

8. Based on the UML diagram, how do we indicate an `extends` relationship in UML?

We add a solid arrow with an open triangle head from the subclass (`MyBigInt`) to the superclass (`BigInteger`). Read: "`MyBigInt` is-a `BigInteger`".

9. The keyword `super` behaves like the keyword `this`, except that it refers to the superclass. On the following lines, which method (in which class) is being invoked?

a) Line 7: constructor in BigInteger

b) Line 11: toString in BigInteger

c) Line 18: toString in StringBuilder

10. Open *MyBigInt.java*. Copy the following code snippets into the `main` method, one at a time (without the others), and run them. Record the results in the table below.

Java Code	Result
`BigInteger bi = new BigInteger("123456789");` `System.out.println(bi);`	123456789
`MyBigInt bi = new MyBigInt("123456789");` `System.out.println(bi);`	123,456,789
`BigInteger bi = new BigInteger("123,456,789");` `System.out.println(bi);`	NumberFormatException
`MyBigInt bi = new MyBigInt("123,456,789");` `System.out.println(bi);`	123,456,789

`BigInteger bi1 = new BigInteger("123456789");`
`MyBigInt bi2 = new MyBigInt("123,456,789");`
`System.out.println(bi1.equals(bi2));`
`System.out.println(bi2.equals(bi1));`
	true
	true

11. Based on these results, summarize what the source code for each method does:

a) `MyBigInt` constructor

It first removes any commas from the given string. It then invokes the constructor of `BigInteger` to initialize the object.

b) `MyBigInt.toString`

It first invokes the `toString` method of `BigInteger`. It then uses a `StringBuilder` to insert commas into the result.

c) `MyBigInt.equals`

It compares the numerical contents of one `BigInteger` with another. (The commas in `MyBigInt` are not stored; they are inserted by `toString`.)

12. Why do you think `bi2.equals(bi1)` compiles and runs correctly, even though the `MyBigInt` class does not define an `equals` method?

`MyBigInt` uses (inherits) the `equals` method from `BigInteger`.

13. Refer to the documentation for BigInteger and the source code for `MyBigInt`. How many public items are defined in each class?

a) `BigInteger` fields: 4

b) `BigInteger` constructors: 8

c) `BigInteger` methods: 50

d) `MyBigInt` fields: 0

e) `MyBigInt` constructors: 1

f) `MyBigInt` methods: 1

14. Type the code on the right in `main` and view possible completions suggested by the IDE.

a) How many constructors does a `MyBigInt` have?
1

b) About how many methods does a `MyBigInt` have?
61 (not counting the `main` method)

```
bi2 = new MyBigInt(
bi2.
```

15. Notice that `MyBigInt` has most of the same fields and methods as `BigInteger`. Non-private fields and methods are ***inherited*** when extending a class. Based on your answers to the previous two questions, what is <u>not</u> inherited? Explain your reasoning.

Constructors are not inherited. `BigInteger` has 8 constructors, but `MyBigInt` has only 1.

16. Make the following changes to *MyBigInt.java*, and summarize the compiler errors.

a) Rewrite the constructor using two lines of code:

```
String str = val.replace(",", "");
super(str);
```

Constructor call must be the first statement in a constructor.

b) Remove all code from the body of the constructor.

Implicit super constructor BigInteger() is undefined.
Must explicitly invoke another constructor.

c) Remove the constructor altogether.

Implicit super constructor BigInteger() is undefined for default constructor.
Must define an explicit constructor.

17. Consider a method `isPalindrome()` that determines whether a `MyBigInt` has the same digits forward and backward. For example, `123,321` and `12,321` are palindromes, but `123,421` and `12,341` are not. How could you implement this method?

```
public boolean isPalindrome() {
    String str = super.toString();
    final int N = str.length();

    // check each pair of digits
    for (int i = 0; i < N / 2; i++) {
        int j = N - 1 - i;
        if (str.charAt(i) != str.charAt(j)) {
            return false;
        }
    }
    return true;




}
```

18. Add your solution to *MyBigInt.java*, and make sure it works. What code can you add to `main` to test the `isPalindrome` method?

```
System.out.println(new MyBigInt("123321").isPalindrome());
System.out.println(new MyBigInt("12321").isPalindrome());
System.out.println(new MyBigInt("123421").isPalindrome());
System.out.println(new MyBigInt("12341").isPalindrome());
```

Model 3 Abstract Classes

Just like in language and philosophy there are abstract ideas and categories that can be realized as concrete examples/things, Java allows us to distinguish between `abstract` classes and ***concrete*** (the default) classes.

```
public class ToySheep {
    private int volume;

    public ToySheep() {
        this.volume = 3;
    }

    public int getVolume() {
        return volume;
    }

    public void setVolume(int volume) {
        this.volume = volume;
        makeNoise();
    }

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

```
public class ToyRobot {
    private int chargeLevel;
    private int volume;

    public ToyRobot() {
        this.chargeLevel = 5;
        this.volume = 10;
    }

    public void recharge() {
        chargeLevel = 10;
    }

    public int getVolume() {
        return volume;
    }

    public void setVolume(int volume) {
        this.volume = volume;
        makeNoise();
    }

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

Questions (25 min) Start time:

19. Identify ***similarities*** in the code: what fields and methods do the classes have in common?

`private int volume, getVolume(), setVolume(int volume), makeNoise()`

20. Summarize ***differences*** between the two classes.

Constructor differences: ToySheep sets volume to 3, but it's 10 in ToyRobot. In `makeNoise()`, ToySheep says "Baaa", but ToyRobot says "Beep Beep!". The ToyRobot has an extra `recharge()` method.

21. Design a new class named `LoudToy` that contains the code that `ToySheep` and `ToyRobots` have in common. Its constructor should take `volume` as a parameter, and `makeNoise` should have an empty body.

```
public class LoudToy {

    private int volume;

    public LoudToy(int volume) {
        this.volume = volume;
    }

    public int getVolume() {
        return volume;
    }

    public void setVolume(int volume) {
        this.volume = volume;
        makeNoise();
    }

    public void makeNoise() {
        // will be overridden in subclass
    }



}
```

22. Redesign `ToySheep` so that it extends `LoudToy`. The constructor of `ToySheep` should call the constructor of `LoudToy`. Remove the code from `ToySheep` that is no longer necessary.

```
public class ToySheep extends LoudToy {

    public ToySheep() {
        super(3);
    }

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



}
```

23. Redesign `ToyRobot` so that it extends `LoudToy`, and remove extraneous code.

```
public class ToyRobot extends LoudToy {

    private int chargeLevel;

    public ToyRobot() {
        super(10);
        chargeLevel = 5;
    }

    public void recharge() {
        chargeLevel = 10;
    }

    public void makeNoise() {
        System.out.println("Beep Beep!");
    }


}
```

24. What is the output of the following examples?

a)
```
LoudToy toy1 = new LoudToy(1);
toy1.makeNoise();
```
(no output)

b)
```
LoudToy toy2 = new ToySheep();
toy2.makeNoise();
```
```
Baaa
```

c)
```
LoudToy toy3 = new ToyRobot();
toy3.makeNoise();
```
```
Beep Beep!
```

Notice that the ***instantiated type*** of an object can be a subclass of its variable's ***declared type***. In other words, we can store `ObjectType` in a variable with declared type `DeclaredType` if and only if `ObjectType` "is-a" `DeclaredType`.

25. In #24, did the variable's ***declared*** type or the object's ***instantiated*** type determine the version of `makeNoise` that was called?

The object's instantiated type—notice that the variable's declared type is the same in all three instances.

26. Would it ever make sense to construct a `LoudToy` object? Why/why not?

Answers will vary, but a `LoudToy` isn't very useful by itself, since all it can do is get and set volume. It needs other attributes and methods to represent an actual toy.

The `abstract` keyword can be used to declare methods that have no body, forcing subclasses to override them. Classes with abstract methods must also be defined as abstract.

```
public abstract class LoudToy {
    private int volume;

    public LoudToy(int volume) {
        this.volume = volume;
    }

    public int getVolume() {
        return volume;
    }

    public void setVolume(int volume) {
        this.volume = volume;
        makeNoise();
    }

    public abstract void makeNoise();
}
```

27. Summarize the differences between Model 3 and your answer to #21.

The class and the `makeNoise` method are declared as abstract. The definition of `makeNoise` ends with a semicolon, rather than an empty body `{}`.

28. Open *LoudToy.java* (from Model 3) in your IDE. Remove the word `abstract` from the class definition. What are the two compiler errors?

The type LoudToy must be an abstract class to define abstract methods.

The abstract method makeNoise in type LoudToy can only be defined by an abstract class.

29. Replace the word `abstract` in the class definition, and then remove the word `abstract` from the method definition. What is the compiler error now?

This method requires a body instead of a semicolon.

30. Remove the definition of `makeNoise` altogether, and notice the compiler error. Why is it necessary to declare this method in `LoudToy`?

The `setVolume` method calls the `makeNoise` method.

31. Undo all changes in *LoudToy.java*, and add the following `main` method. What is the compiler error message? Why do you think Java doesn't allow you to construct a `LoudToy`?

```
public static void main(String[] args) {
    LoudToy toy1 = new LoudToy(1);
    toy1.makeNoise();
}
```

The compiler says, "Cannot instantiate the type LoudToy." Abstract classes cannot be instantiated, because some of their methods aren't implemented.

32. Open *ToySheep.java* and rename `makeNoise` to `makeNoise2`. What is the compiler error?

The type ToySheep must implement the inherited abstract method LoudToy.makeNoise().

33. Rename the method back to `makeNoise`, but change `void` to `int`. What is the error now?

The return type is incompatible with LoudToy.makeNoise().

34. Explain how an abstract method is like a contract.

If you inherit an abstract class, you must override the abstract methods exactly as defined. This is important because they might be called in the code of the abstract class.