Classes to Organize Code

Programs can become very large and complex. Much of the software you are used to using includes tens of millions of lines of code – Windows, MacOs, Microsoft Office and WPS Office, Chrome, Edge, Safari. Even the average Android or Apple phone application is 50,000 to 100,000 lines of code – even without the libraries, like the UI frameworks, that they use.

Considering this, it is extremely important to be able to organize code. *Object-oriented* programming organizes portions of code that perform a particular function into its own class.

In Java, each `public class` must be contained within it's own file, and the file name of that file must match the name of the class, followed with a "`.java`" extension. One class that we've used before is the Java `Math` class. Look at example code which, although not exactly the same as what is in the real `Math` class, implements a portion of it, and is functionally equivalent.

***Code Block 1**: Code implementing functionality of the Java `Math` class*

```
1  public class Math {
2     public static final double PI = 3.14159265358979323846;
3     public static double abs(double a) {
4        if(a >= 0) {
5           return a;
6        } else {
7           return -a;
8        }
9     }
10 }
```

A ***constant*** is a value that, once set, cannot change during the execution of the program. In Java, a *constant* is defined and initialized in the same way a *variable* is, except the keyword `final` is added before the type of the data. Line `2` of the code above defines a value for π, assigning it to a *constant* of type `double` that has the identifier `PI`.

When a *constant* or a *variable* is defined at the top level within a class, it is called a ***field*** (or sometimes an ***attribute***).

We can access a `static` *field* that is in a different class than the current class by using the class identifier, a period (`.`), then the *field* identifier. For example, we can use the value of the `PI` constant from within a class other than the `Math` class by typing `Math.PI` in the code. *Code Block 2* shows an example of this.

Line `3` of *Code Block 1* defines a `static` method named `abs` that takes a single parameter of type `double`, and returns a value that is also of type `double`. We call this method from a class other than the `Math` class in a similar way: with the class name, a period, then the method identifier and the parameters required by the parameter list in the method signature. So to call the `abs` method and pass a `double` value of `-5.25` to it, we would type: `Math.abs(-5.25)`. Again, *Code Block 2* shows an example of this (using a variable named `d` of type `double` to store the value passed.

***Code Block 2**: Code using the `Math` class, and corresponding output*

```
1 public class UsingMath {
2    public static void main(String[] args) {
3       double d = -5.25;
4       System.out.println("The value of pi is: " + Math.PI);
5       System.out.println("Absolute value of " + d +
6                          " is " + Math.abs(d));
7    }
8 }
```

```
Absolute value of -5.25 is 5.25
The value of pi is: 3.141592653589793
```

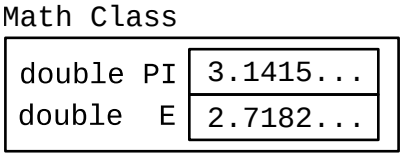
You should already have a solid understanding of how the code from *Code Block 2* works. Ensure you have studied *Code Block 1: Code implementing functionality of the Java Math class* sufficiently to understand how a Java class is written so that you can organize your own code by separating different functionality into different classes.

Static Versus Non-Static

In the previous section, we have discussed `static` fields and methods. Shortly, we will discuss non-`static` fields and methods. For `static` fields, there is one value stored in memory for each class. For example, the `Math` class need only have a single constant named `PI` that can be used by any other code. There is no need to create multiple instances of the `Math` class in order to have multiple values for `PI`.

However, the `String` class is different. We will surely want more than one value of string in almost every program we write. The `String` class defines the data structures and methods that operate on ***instances*** of the `String` class. How this is implemented in Java will hopefully be clear to you soon.

The following shows diagrammatically how the data for the `Math` class and for two instances of the `String` class are stored.

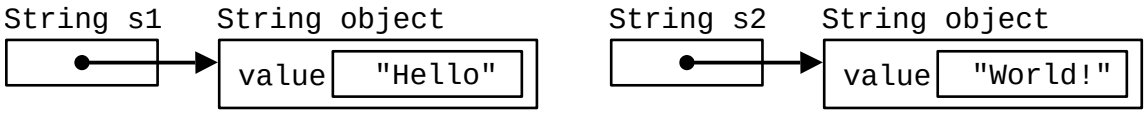


For the `Math` class, the `static` values are associated with the class. We do not create any *instances* of the Math class.

You may recall how we previously created instances of the String class with the code similar to:

```
String s1 = new String("Hello");
String s2 = new String("World!");
```

For the `String` class, *instances* of type `String` are created, and each instance stores its own data values. When *fields* are non-`static`, each ***instance*** of the class stores a different value.



With static fields, such as `Math.PI`, we use the class identifier to reference it. There is no ambiguity since there is only one value for the class. However, if we were to try to use the class identifier when referring to non-`static` fields, such as using `String.value` when referencing to a string object, how would the compiler know whether you are referring to the value "`Hello`" in the `s1` `String` object or the value "`World!`" in the `s2` `String` object?

To ensure there is no ambiguity, we must use the variable identifier (not the class identifier) when we refer to non-`static` fields and methods of an object. For example, we cannot use `String.length()`, that will return an error. We must use `s1.length()` to return the value of `5`, the length of the string "`Hello`", and `s2.length()` to return a value of `6`, the length of the string "`World!`".

This concept is fundamental, yet perhaps difficult, and it will hopefully be more clear as we go through more examples.

Using Classes to Define Complex Data Structures

Imagine we are writing some physics software that will manipulate vectors. One early requirement is that we are able to add two vectors. So let's consider how this might work. You start thinking of how you might write this and soon you find an inconvenience. Examine the code below and find the error. Then consider if you know of any easy and elegant way to solve the problem.

***Code Block 3**: First draft of method `addVector()` – contains an error!*

```
1  public class TestVector {
2     public static void main(String[] args) {
3        double x1 = 5;
4        double y1 = 4;
5        double x2 = -1;
6        double y2 = -1;
7        double v = addVector(x1, y1, x2, y2);
8        System.out.println("Vector value: " + v);
9     }
10    public static double addVector(double x1, double y1,
11                                   double x2, double y2) {
12       double x3 = x1 + x2;
13       double y3 = y1 + y2;
14       return x3, y3;
15    }
16 }
```

In Java, we cannot have multiple return values from a function. This makes it very inconvenient to deal with data structures that are more than just a single primitive type. There are different solutions possible, but one solution is ***object-oriented programming***. The first step is to create an ***object*** that

can store data that belongs logically together in one place. We start by defining the structure of the object we wish to create in a `class`.

In the above example, our data structure is a vector, and a two-dimensional vector consists of an x component and a y component. Each of the x and y components can be stored in their own variable of type `double`. The code below is how we might use a class named `Vector` to define what data a `Vector` object contains.

***Code Block 4**: First draft of the `Vector` class*

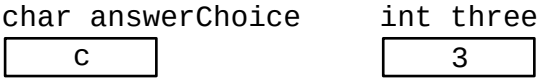
```
1 public class Vector {
2    public double x;
3    public double y;
4 }
```

The variables `x` and `y` are defined immediately inside the class at the top level (i.e.: not inside a method). These top-level variables defined in a class are called ***fields***.

Recall that we declare an initialize primitive type variables with statements such as these.

```
1 char answerChoice = 'c';
2 int three = 3;
```

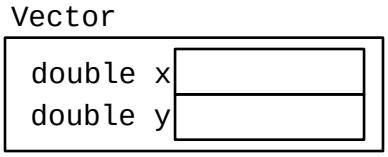
Memory is allocated and the value is stored in the memory location referred to by the variable identifier. These could be represented diagrammatically as:



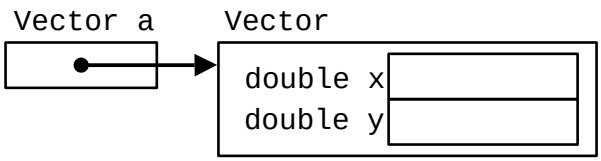
For objects, we declare and initialize an object variables with a statement such as this:

```
1 Vector a = new Vector();
```

The latter part of the line contains the keyword `new`, followed by the class name – in this case `Vector` – and a set of parentheses. This part of the code allocates the space to store the data inside the class. This data structure might be represented diagrammatically as:



The assignment (`=`) then stores the *reference* to (memory location of) that data into a variable with identifier `a`. The final data structure is shown diagrammatically below.



Notice that while primitive types store their value directly in the memory location given by the variable identifier, object variables only store a ***reference*** to (the location of) the data. The actual data is stored in a separate area of memory. The reason for this is that it allows all object variables to be the exact same size, no matter how big or small the actual object is.

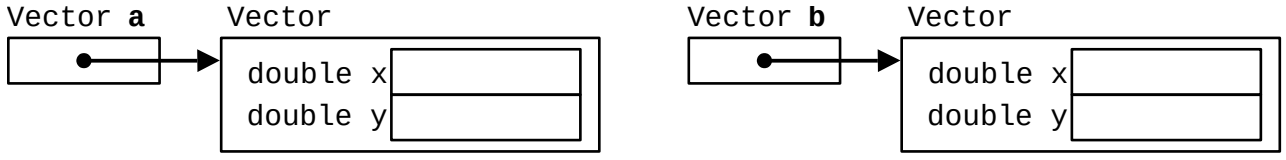
Using Public Fields From a Separate Class

Both *fields* in the Vector class in *Code Block 4* have the modifier `public`. The `public` modifier allows the fields to be accessed directly from any other class, as is shown with the following code block.

***Code Block 5**: Second draft of method `addVector()`*

```
1  public class TestVector {
2     public static void main(String[] args) {
3        Vector a = new Vector();
4        Vector b = new Vector();
5        a.x = 5;
6        a.y = 4;
7        b.x = -1;
8        b.y = -1;
9        a = addVector(a,b);
10       System.out.println("Vector value: (" +
11                          a.x +", " + a.y + ")");
12    }
13    public static Vector addVector(Vector v1, Vector v2) {
14       Vector v = new Vector();
15       v.x = v1.x + v2.x;
16       v.y = v1.y + v2.y;
17       return v;
18    }
19 }
```

Lines 3 and 4 will allocate memory for two separate Vector objects, and assign the location of one to variable `a`, and the location of the other to variable `b`. A diagrammatic representation of this is shown below.



Lines `5` through `8` show how the `public` ***instance*** *fields* within an *object* can be accessed. Be aware that we do <u>not</u> use the class identifier when accessing the data within an object, as we do to access `static` class fields, but we must use the object (variable) identifier. The object identifier, a period (`.`), and the identifier of the field to be accessed.

Line `13` contains the *method header* for `addVector`. The return type is an object of type `Vector`. This way, we are able to return a complex data structure from a method, not only a primitive type. We are also able to pass complex data types (objects) into a method in the parameter list, which can often simplify the parameter list and provide a level of abstraction.

Constructors to Initialize Objects

You might recall that when we *instantiated* a `String` object using the `new` keyword, we put the value for the string directly into the parentheses after the class name:

```
String s = new String("Hello");
```

We can also do this when we instantiate a `Vector` object by adding a ***constructor*** to our `Vector` class. A ***constructor*** is a method used to initialize the ***state*** of (the values stored in) an *instance* of the class. In Java, the identifier of every constructor must be the exact same as the identifier of the class is is in. In this case, our class identifier is `Vector`, so the constructor identifier must also be `Vector`. *Code Block 6*, below, has a constructor added to our previous version of the `Vector` class.

***Code Block 6**: Second draft of the `Vector` class*

```
1 public class Vector {
2    public double x;
3    public double y;
4    public Vector(double x, double y) {
5       this.x = x;
6       this.y = y;
7    }
8 }
```

For any `Vector` object, there are two fields: `x` and `y`, each of which is of type `double`. The constructor takes in two parameters, also named `x` and `y`, and also each of type `double`. The statement "`this.x = x;`" assigns the value passed into parameter `x` into the instance field `x`.

The "`this.x`" is required to remove the ambiguity that arises from using the same name for the instance field as for the constructor parameter. The "`this`" is not required if a different name were used for the parameter. For example the following code is also valid.

```
1 public class Vector {
2    public double x;
3    public double y;
4    public Vector(double xValue, double yValue) {
5       x = xValue;
6       y = yValue;
7    }
8 }
```

The following is updated code to use the constructor that was added to the `Vector` class. The constructor call has be highlighted using bold font.

***Code Block 7**: Test code for second draft of the `Vector` class*

```
1  public class TestVector {
2     public static void main(String[] args) {
3        Vector a = new Vector(5.0, 4.0);
4        Vector b = new Vector(-1.0, -1.0);
5        a = addVector(a,b);
6        System.out.println("Vector value: (" +
7                           a.x +", " + a.y + ")");
8     }
9     public static Vector addVector(Vector v1, Vector v2) {
10       Vector v = new Vector(0.0, 0.0);
11       v.x = v1.x + v2.x;
12       v.y = v1.y + v2.y;
13       return v;
14    }
15 }
```

If there is no constructor definition in a class, the Java compiler will add a “default constructor”. The default constructor takes no parameters, and assigns a value of zero to all instance fields for any instantiated object. If a constructor is written for a class, then no default constructor will be added. Thus, although we could previously instantiate an object of type Vector using the line:

```
Vector a = new Vector();
```

After adding the constructor that requires two parameters of type `double` to the class, any attempt to call the constructor for `Vector` with no parameters (as in the line above) will result in a compile-time error.

Classes to Encapsulate Functionality

The method we have written, `addVector`, operates on two `Vector` objects. Therefore, we can only ever use it when we are manipulating objects of type `Vector`. We may also write other methods that will operate on `Vector` objects. It makes much more sense to keep all things related to manipulating `Vector` objects together in one place, and also together with the definition of what a `Vector` is. Meaning: we should move the method for adding `Vector` objects into the `Vector` class. This leads us to our next draft of the `Vector` class and associated test code.

***Code Block 8**: Third draft of the `Vector` class*

```
 1 public class Vector {
 2    public double x;
 3    public double y;
 4    public Vector(double x, double y) {
 5       this.x = x;
 6       this.y = y;
 7    }
 8    public void add(Vector v) {
 9       this.x += v.x;
10       this.y += v.y;
11    }
12 }
```

***Code Block 9**: Test code for the third draft of the `Vector` class*

```
1 public class TestVector {
2    public static void main(String[] args) {
3       Vector a = new Vector(5.0, 4.0);
4       Vector b = new Vector(-1.0, -1.0);
5       a.add(b);
6       System.out.println("Vector value: (" +
7                          a.x +", " + a.y + ")");
8    }
9 }
```

Printing Objects

Consider the code in *Code Block 10*, below. Unlike the previous test code, here we are calling `println` with a `Vector` object as a parameter.

***Code Block 10**: Test code for printing a `Vector` object*

```
1 public class TestVector {
2    public static void main(String[] args) {
3       Vector a = new Vector(5.0, 4.0);
4       Vector b = new Vector(-1.0, -1.0);
5       a.add(b);
6       System.out.println(a);
7    }
8 }
```

The output of this code, with the Vector class as defined in *Code Block* 8 will be something similar to the following:

```
com.nielsenedu.apcsa.unit5.vector.Vector@3f8f9dd6
```

As we can see, the output when we call `System.out.println` to print our `Vector` object is likely not what we'd expect or want. So what happened and how can we make our program print something more useful?

When we call `System.out.println` with an object as a parameter, the object's `toString` method is called to obtain a `String` representation of the object to print. But what if an object does not have a `toString` method defined? (Just as our `Vector` class does not have a `toString` method explicitly defined in it.)

All objects in Java will have a `toString` method defined, because any object that does not explicitly define a `toString` method will ***inherit*** the `toString` method that is defined in the `Object` class. Since ***inheritance*** is a later topic in the course, we will not go into how this works here – just know that there will be a `toString` method for every object. However, since the `toString` method defined in the `Object` class is not very useful to us, we will ***override*** this `toString` method with a better one.

***Code Block 11**: Fourth draft of the `Vector` class – with `toString`*

```
1  public class Vector {
2     public double x;
3     public double y;
4     public Vector(double x, double y) {
5        this.x = x;
6        this.y = y;
7     }
8     public void add(Vector v) {
9        this.x += v.x;
10       this.y += v.y;
11    }
12    @Override
13    public String toString() {
14       return "(" + this.x + ", " + this.y + ")";
15    }
16 }
```

Note that the "`@Override`" compiler directive is optional and not part of the Java AP Subset. The output of this `Vector` class code, using the test code in *Code Block* 10, follows:

```
(4.0, 3.0)
```

Writing a `toString` method will often be very useful for making one's test code simpler and cleaner.

Making Fields Private

Consider the following code.

***Code Block 12**: Definition of the `AverageCalculator` class and its test class*

```
 1 public class AverageCalculator {
 2    public double sum;
 3    public int count;
 4    public void add(double n) {
 5       sum += n;
 6       count++;
 7    }
 8    public double get() {
 9       return sum/count;
10    }
11 }
```

```
 1 public class TestAverageCalculator {
 2    public static void main(String[] args) {
 3       AverageCalculator average = new AverageCalculator();
 4       for(int i = 5; i <= 10; i++) {
 5          average.add(i);
 6       }
 7       average.count = 2;
 8       System.out.println(avg.get());
 9    }
10 }
```

Any `public` field within a class may be read and written directly by other classes. For example, since the `count` field of `AverageCalculator` is declared as `public` (on line 3), the field may be accessed externally by another class, as the `TestAverageCalculator` class does on line 7.

If we consider the purpose of the `AverageCalculator` class, the class is only certain to calculate a valid average of the added numbers if the fields are not modified by an external class. Really, there is no good reason for an external class to modify the fields of this class directly. The fields should be protected – access and modification should be restricted, and all functionality associated with the object should be contained within the object. This practice is called ***encapsulation***.

As there is no good reason for other classes to access the fields of the `AverageCalculator` class directly, we change the access modifier tag of both the `sum` and `count` fields to `private`. When a class has `private` fields, these fields cannot be read or written directly – line 7 of the `TestAverageCalculator` class will then be an error.

It is considered good practice to always make instance fields of a class `private`, unless there is a reason to not do so. For completeness, the updated code for the `AverageCalculator` class and its test code is given below.

***Code Block 13**: The `AverageCalculator` class (with private fields), and its test class*

```
1  public class AverageCalculator {
2     private double sum;
3     private int count;
4     public void add(double n) {
5        sum += n;
6        count++;
7     }
8     public double get() {
9        return sum/count;
10    }
11 }
```

```
1  public class TestAverageCalculator {
2     public static void main(String[] args) {
3        AverageCalculator average = new AverageCalculator();
4        for(int i = 5; i <= 10; i++) {
5           average.add(i);
6        }
7        System.out.println(average.get());
8     }
9  }
```

Accessor Methods

For the `AverageCalculator` class, other classes are not able to read or modify the fields directly. Modifying either field would affect the proper operation of the class. However, there may be situations where it would be useful for another class to know how many values were involved in calculating the average. Unfortunately, once we make a field `private`, it can neither be modified nor read (accessed) from outside the class. If we wish to know the value a `private` field has, we must write an ***accessor*** method.

An ***accessor*** method, also called a ***getter*** method, is simply a method that returns the value of a field. It is common practice to name an accessor method by appending the field name to the prefix "`get`", adjusting the case so that the method uses proper camel case. Thus, method providing access to the field `count` should be named "`getCount`". It should be obvious that an accessor method will be `public`, and the return type will be the same as the field that it is providing access to.

Below is the updated `AverageCalculator` class with an accessor, highlighted in bold font, allowing other classes to the number of values that were added in order to calculate the average. When a field is `private`, and has an accessor method but no mutator method, the field may be read but not written. The count field of the `AverageCalculator` class is a read-only field.

***Code Block 14**: The `AverageCalculator` class (with private fields), and its test class*

```
 1 public class AverageCalculator {
 2    private double sum;
 3    private int count;
 4    public void add(double n) {
 5       sum += n;
 6       count++;
 7    }
 8    public double get() {
 9       return sum/count;
10    }
11    public int getCount() {
12       return count;
13    }
14 }
```

Mutator Methods

A ***mutator*** method, also called a ***setter*** method, is simply a method that allows controlled modification of a field. It is common practice to name an mutator method by appending the field name to the prefix "`set`", adjusting the case so that the method uses proper camel case. Thus, method providing modification of the field `password` should be named "`setPassword`". It should be obvious that an accessor method will be `public`. The return type for a mutator method is often `void`, however other values may be returned such as a `boolean` value that represents whether the modification was successful or not, or perhaps an `int` return value that gives an error code for diagnosing the reason for a failure.

As an example of a class that would require a mutator (setter) method but not an accessor (getter) method, we will consider the following `Password` class.

***Code Block 15**: The `Password` class*

```
1 public class Password {
2    private String hashedPassword;
3    public void setPassword(String password) {
4       this.hashedPassword = Cryptography.hash(password);
5    }
6    public boolean verifyPassword(String password) {
7       return Cryptography.verify(hashedPassword, password);
8    }
9 }
```

It is standard practice to never save raw passwords on computers. Instead, a non-reversible cryptographic calculation is performed on the password (called a hash), and that value is stored. During password validation, the same calculation is performed on the given password and the resulting hash is compared to the stored hashed password.

In the `Password` class, above, a mutator (setter) method is made available to store the value given in `password`; however the actual password is not stored as entered, but rather a hash of the password is stored. It doesn't make sense to provide an accessor (getter) method for the value `password` – not only because the password should be secret, but also because it isn't even stored!

This `Password` class is still useful because it provides a method, `verifyPassword`, that will allow the software to validate whether a password entered is correct. It allows software to save and verify passwords without the possibility that the secrecy of the password could be compromised.

Accessors and Mutators (Summary)

It is considered good practice to make all instance fields `private`. Doing so allows a class to maintain the integrity of the data (make sure the data values are accurate and uncorrupted) and perform data validation (checks to ensure data is valid when the fields are modified).

As is deemed necessary for functionality, a class may provide read access to a field by providing an accessor (getter) method, and may provide write access to a field by providing a mutator (setter) method. Any field may have either an accessor, a mutator, or both methods.

It is very common for mutator methods to do some data validation – processing and checking of the input – before setting the field according to the request.

Accessor methods may simply return a field, or they may do some processing of the fields before returning the value.