Chapter 2

Creation and Storage of JAVA Objects

What is in This Chapter ?

When beginning object-oriented programming, students often have difficulty understanding how objects interact. As a result, students sometimes struggle to write code in an object-oriented manner. In this chapter we discuss how objects are created, stored and used in JAVA. In order to properly understand object-oriented programming, it is important for you to understand where data is being stored and how to access the data that is within another object. Once you understand this simple concept, your life as an object-oriented programmer will be easier. We will also discuss memory allocation so that you fully understand what an object actually is. This will help you in 2nd year when you have to allocate memory on your own.
2.1 Using Existing JAVA Objects

Until now, we have discussed creating programs by creating a class and inserting all of our code into a main() procedure/method. This means that our programs are considered procedural. Object-Oriented Programming (OOP) is similar to that of procedural programming in that it also involves executing a set of instructions in some specified order. However, it differs from procedural programming in the way that your code is organized.

Programming using object-oriented style, involves organizing your code in "chunks" that logically correspond to real-world objects. For example, you may group all of your code related to a person into one file (called a class) while code related to a car or a bank account would be grouped together in separate files (i.e., classes).

JAVA actually has a lot of pre-defined objects that are all organized into various packages. A package is essentially equivalent to a folder that contains your .java files. There are many standard packages in JAVA, each with many classes.

Here are just some of the standard packages that you will likely use in this course:

<table>
<thead>
<tr>
<th>Package</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>java.lang</td>
<td>Basic classes and interfaces required by many JAVA programs. It is automatically imported into all programs.</td>
</tr>
<tr>
<td>java.util</td>
<td>Utility classes and interfaces such date/time manipulations, random numbers, string manipulation, collections ...</td>
</tr>
<tr>
<td>java.io</td>
<td>Classes that enable programs to input and output data.</td>
</tr>
<tr>
<td>java.text</td>
<td>Classes and interfaces for manipulating numbers, dates, characters and strings. Provides internationalization capabilities as well.</td>
</tr>
</tbody>
</table>

When you want to make use of some of these classes, you will use the import keyword to tell JAVA that you want to use a class so that it knows where to find it:

```java
import <packageName>.*;
```

We did this already when we used the Scanner class, which is in the java.util package. Basically, the import statement is used to tell the compiler which package (i.e., directory) the class files are sitting in. You can always replace the * by a class name (where the class name is in the package) so that the readers of your code are more clear on which classes you are actually using. Keep in mind though that the import statement does not load any classes, it merely instructs the compiler where to find them when you run your code. The code is only imported.loaded by the JVM from those libraries as it is needed.

Here is a simple example that makes use of the pre-defined Object, String, Date, Point and Rectangle object classes in JAVA, making sure to import the correct package:
import java.lang.Object;
import java.lang.String;
import java.util.Date;
import java.awt.Point;
import java.awt.Rectangle;

public class ObjectTestProgram {
  public static void main(String[] args) {
    System.out.println(new Object()); // general object
    System.out.println(new String()); // blank string
    System.out.println(new Date()); // date object
    System.out.println(new Point(50, 75)); // point object
    System.out.println(new Rectangle(5, 10, 20, 30)); // rectangle
  }
}

If we do not specify where to find the objects via the import statement, JAVA will become confused when compiling our code and will generate compile errors such as this:

    Error: C:\...\ObjectTestProgram.java:12: cannot find symbol class Date

In fact, all classes in the java.lang package are automatically imported so we do not need the first two import statements. Also, when we have multiple classes being imported from the same package (e.g., Point, Rectangle), we can use a single import statement with the * wildcard character to tell JAVA to import any needed classes from that package. So here is the simplest form of the code:

import java.util.*;
import java.awt.*;

public class ObjectTestProgram {
  public static void main(String[] args) {
    System.out.println(new Object()); // general object
    System.out.println(new String()); // blank string
    System.out.println(new Date()); // date object
    System.out.println(new Point(50, 75)); // point object
    System.out.println(new Rectangle(5, 10, 20, 30)); // rectangle
  }
}

In this example, we are simply creating the objects and then displaying them. Notice how these objects are displayed in the output:

java.lang.Object@d93b30
Mon Jan 09 20:30:35 EST 2017
java.awt.Point[x=50,y=75]
java.awt.Rectangle[x=5,y=10,width=20,height=30]
Each object displays itself differently. Notice that the `Date` object that was created actually corresponds to today’s date and time (i.e., on January 9, 2017 when I ran the code). Also, notice that the `String` object was actually an empty string (i.e., no characters were displayed).

### 2.2 Creating Your Own Objects in JAVA

In the previous course, you may have already gained experience in defining your own data structures (a.k.a. **data types, objects**) that you used within your program in order to group various data elements together. For example, you may have created a data structure that represents someone's address in a similar manner as shown here.

```java
class Address {
    String name;
    int streetNumber;
    String streetName;
    String city;
    String province;
    String postalCode;
}
```

In JAVA, we create this object by defining a `class`. Each class that we define represents a new type (or category) of object. So, the above class represents an `Address` object that we have defined. Here is a simple definition of an object as we know it so far:

*A object represents multiple pieces of information that are grouped together.*

A primitive data type (e.g., int, float, char) represents a single simple piece of information. An object, however, is a bundle of data, which can be made up of multiple primitives or possibly other objects as well. You can think of an object as a bunch of small pieces of information with elastic bands around them to hold them together as a single object (as shown here). Once we define this class/object, then we were allowed to create `Address` objects and use them within our programs. For example, here is how we can create a new `Address` object and fill in its values:

```java
Address addr;

addr = new Address();
addr.name = "Patty O'Lantern";
addr.streetNumber = 187;
addr.streetName = "Oak St.";
addr.city = "Ottawa";
addr.province = "ON";
addr.postalCode = "K6S8P2";

System.out.print(addr.name + " lives at ");
System.out.println(addr.streetNumber + " " + addr.streetName);
```
The code above prints out: "Patty O'Lantern lives at 187 Oak St."

In JAVA, we generally define all of our own objects in separate .java files which will reside in the same folder as the main program class:

Even though the Car and House objects are defined in their own individual .java files, they cannot be run as programs. You can only run classes that have the public static void main(...) method defined. So, a JAVA program will typically consist of multiple .java files ... many of them being object definitions, and one of them being the actual program itself.

For example, we can define very simple Car and Person objects along with a test program as follows (remember that each class is defined in its own file):

```java
public class Car {
    String make;
    String model;
    int year;
}

public class Person {
    String name;
    String phoneNumber;
}

public class MyObjectTestProgram {
    public static void main(String[] args) {
        System.out.println(new Car());
        System.out.println(new Person());
    }
}
```

Notice now the output from the program:

```
Car@19821f
Person@42e816
```

This is what objects look like by default. They show the name of the class, then an @ symbol, and finally a strange combination of numbers and letters.
This number/letter combination represents the location (or address) of the object in the computer’s memory. We call this the reference, because this memory address “refers to” the object. The actual value of the address is unimportant to us, however, it is important for you to understand that each time we make an object, it “uses up” a portion of the computer’s memory.

Later we will see how to change the appearance of our objects so that they show more meaningful information when displayed.

The next section of notes will clarify in more detail exactly how these objects are stored in memory.
2.3 Memory Allocation and Object Storage

In order to understand how objects are stored, it is first necessary to understand how your computer’s memory gets "used-up" as your program runs. The Java Virtual Machine (JVM) is allotted a certain amount of memory space on your computer when your program begins to run. The amount of memory allotted is adjustable via command-line arguments.

Upon start-up, some of this allotted memory is used up by the JVM. The remaining memory that is available for your program is denoted as "free memory". As your program runs, it will allocate (i.e., use up) some of this free memory at various times throughout the runtime of the program. Your program will also return (i.e., free up) this used memory at various times as it completes portions of your program. Hence the amount of available free memory will shrink and grow throughout the execution of the program.

If we consider a snapshot at any time, the memory is broken up into 4 main logical portions as shown here:

1. The Static Area of memory is memory that is used by the global & static variables that are defined by your program. This memory usage is fixed and does not change as the program runs.

2. The Free Memory is the memory that is not currently being used by your program. If this memory ever gets used up during your program, you will get an "Out Of Memory" error and your program will stop running.

3. The Stack memory is the memory that is used to store local variables. It also gets used up a little each time you call a method or run code within a block of code (i.e., a block is any code within braces). The amount of memory used during a method call depends on the number and size of the local variables defined in the method as well as its parameters.

4. The Heap memory is the memory that stores all the objects that you create. Each time that you call a constructor by using the new keyword, the Heap memory will increase.

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JAVA Memory Model

![JAVA Memory Model Diagram](image)

- **Global & static variables**
- **Created objects**
- **FREE MEMORY**
- **LOCAL VARIABLES**
- **STRICTLY GLOBAL**
- **STRICTLY STATIC**
- **STRICTLY LOCAL**
- **HEAP**
- **STACK**

---
The following diagram shows how the Stack and Heap memory grows and shrinks over time:

Interestingly, in JAVA, there is no way explicitly to free up heap memory from objects that you no longer want to use. The garbage collector handles this for you. You can "suggest" that the garbage collector free up memory at any time in your program by using System.gc(). However, this does not ensure that garbage collection will take place immediately. It is often suggested to set object-type (i.e., non primitive type) variables to null so that the garbage collector will realize that you are no longer holding on to an object and can free it sooner. Ultimately, the success of this strategy depends on how the garbage collector has been implemented.

For now, let us try to understand how data is stored in the stack memory.
Here are the 8 primitive data types in JAVA and the amount of memory that each requires:

<table>
<thead>
<tr>
<th>Type</th>
<th>Bytes Used</th>
<th>Can Store Values Within This Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>byte</td>
<td>1</td>
<td>-128 to +127</td>
</tr>
<tr>
<td>short</td>
<td>2</td>
<td>-32,768 to +32,767</td>
</tr>
<tr>
<td>int</td>
<td>4</td>
<td>-2,147,483,648 to +2,147,483,647</td>
</tr>
<tr>
<td>long</td>
<td>8</td>
<td>-9,223,372,036,854,775,808 to +9,223,372,036,854,775,807</td>
</tr>
<tr>
<td>float</td>
<td>4</td>
<td>-10$^{38}$ to +10$^{38}$</td>
</tr>
<tr>
<td>double</td>
<td>8</td>
<td>-10$^{308}$ to +10$^{308}$</td>
</tr>
<tr>
<td>char</td>
<td>2</td>
<td>any ASCII or UNICODE character (e.g., 'A','a','1','*','&gt;', etc..)</td>
</tr>
<tr>
<td>boolean</td>
<td>1</td>
<td>true or false</td>
</tr>
</tbody>
</table>

Each time we declare a variable within a method, it reserves enough space in the STACK memory to store the data.

For example, consider the following variables declared within a method (i.e., these are NOT object attributes) and notice the amount of memory that it consumes in the stack memory:

```
byte byte; // age;
int int;   // id;
double double; // weight;
boolean boolean; // retired;
char char;   // gender;
```

JAVA automatically reserves this space for us when we declare these variables. Each variable begins at a unique address in the computer's memory (i.e., the number shown on the left side). When using the variables, in our program, the value for the variable is obtained by simply looking at the address location to obtain the information. Similarly, when assigning values to the variables, the address is used to know where to start storing the information.
Consider now a `Person` object that stores only primitive data type attributes as follows:

```java
public class Person {
    byte age;
    int id;
    double weight;
    boolean retired;
    char gender;
}
```

Notice how the object would be stored in memory on 32-bit and 64-bit machines if we were to declare a few variables of type `Person` as follows:

```java
Person mySister;
Person myMom;
Person myDad;
```
Notice that on a 32-bit machine each variable requires just 4 bytes ... and requires 8 bytes on a 64-bit machine. These bytes represent pointers to the location in memory that the object will actually reside. A 32-bit machine has a 32-bit address space ... and so 4 bytes are required to store each address reference (i.e., just the variable that holds the object ... not the object’s contents). A 64-bit machine has a 64-bit address space ... and so each object variable requires an extra 4 byte overhead (i.e., double the space). So 64-bit machines, although they may be faster for CPU-related operations, may require more space allocation by default (there are ways to "compress" the pointer references...but this is not discussed here). From this point onwards in the notes, unless otherwise stated explicitly, we will assume that we are using a 32-bit machine in order to simplify the discussion.

You will also notice that the space is not reserved for storing any of the actual data inside the object. Storing the data inside the object would require 16 bytes of storage to store the age (1 byte), id (4 bytes), weight (8 bytes), retired (1 byte) and gender (2 bytes) information. However, this space is not reserved until the object is created by calling its constructor.

By declaring the variable: Person mySister; we get a reference mySister (or pointer) to the location of the object in memory. Since we have yet to create the object ... the value of the pointer is null.

So, null actually represents an undefined memory address which requires 4 bytes of storage at all times (64-bit machines require 8 bytes to store each pointer). That means, each time that we will use objects in java, there is always a 4-byte overhead (8-byte for 64-bit machines) to store the reference to the object.

Now what about the object itself? Consider what happens when we create the object via a constructor as follows:

    mySister = new Person();

This is now a constructor call, so the memory that will be used to store the object's data will be the HEAP memory:

The amount of memory used up depends on the object's data values. Looking at the class definition of the Person object, you will notice that it contains only primitive data types ... each of which has a fixed size.

    public class Person {
        byte age;     // 1 byte
        int id;       // 4 bytes
        double weight; // 8 bytes
        boolean retired; // 1 byte
        char gender;  // 2 bytes
    }
The object requires **16 bytes** to store your data. However, each created object in JAVA requires an additional storage overhead of **8 bytes** to store an object header. The data contained in the header is implementation-specific ... so it depends on the particular java implementation that you are using. In fact, it is possible that other java implementations may even vary the amount of space used in the header.

Also, in some cases, additional bytes are allocated in memory to ensure that the entire object uses a multiple of **8 bytes**. That is, our current Person object stores **16 bytes** of data ... a nice multiple of 8. However, if we were to add an additional boolean attribute to the Person object definition, for example, then it would take up **17 bytes**. In that case, java will probably reserve an additional **7 bytes** more to bring the total up to **24 bytes** so that the entire object again uses a multiple of **8 bytes**. These extra **7 bytes** would be unused, but nevertheless allocated.

So, each Person object that we create will require \((16 + 8 = 24)\) bytes of storage as shown in the diagram here. Notice that the mySister variable now points to the location where the Person object is being stored (i.e., address 0008237846 in our example). So, the integer value of **0008237846** will be stored as the pointer at address location **0000024389**. Whenever we therefore use the mySister variable, JAVA just looks at its value and follows the pointer to find the object.
What happens when we access the internals of the `Person` object by using the `dot` operator?

```java
mySister.age = 15;
if (mySister.weight > 150) {
    ...
}
```

The code above requires us to go inside the object to modify its internal `age` variable/attribute and also to access the internal `weight` variable/attribute:

In order to do this, JAVA needs to determine the memory location of the `age` and `weight` attributes relative to the location of the `mySister` Person object.

JAVA begins with the address stored in the `mySister` variable (i.e., 008237846) and then adds to that value the fixed offset that the `.age` portion of the object is with respect to the start of the object (i.e., adds 8 bytes more to bypass the header). The result is 0008237846 + 8 = 0008237854. Once it has this location computed, it can then change the byte value there to 15 as the code instructed.

Similarly, when accessing the `.weight` portion of the object, the offset from the start of the object is 8 + 1 + 4 = 13 bytes. Hence the weight value is found at address location 0008237846 + 13 = 0008237859. Accessing the `double` at this address requires the 8 bytes from address 0008237859 to 0008237866 to be interpreted as a `double` value.
Now what happens when an object is contained within another object? Consider two simple objects defined as follows:

```java
public class GPSLocation {
    float latitude;
    float longitude;
}

public class University {
    short opened;
    String name;
    GPSLocation location;
}
```

Now consider the following code:

```java
GPSLocation herzberg;
University carleton;
herzberg = new GPSLocation();
herzberg.latitude = 45.382149;
herzberg.longitude = -75.697304;

carleton = new University();
carleton.opened = 1942;
carleton.name = "Carleton";
carleton.location = herzberg;
```

Notice what the memory allocation will look like for this example (the picture is condensed a little vertically to fit onto the page) ---->
You can see that there are three objects involved:

- the String literal "Carleton"
- the GPSLocation
- the University

The carleton variable points to the University object … which itself contains pointers to the String object … and the GPSLocation object. The herzberg variable also points to the GPSLocation object and so the address value stored at locations 000024389 and 0508237842 are the same … which is 0508237846.

String literals (i.e., String created using double quotes in your code) not stored in the Heap memory but are actually stored in the STATIC AREA as constants. Any other created Strings are stored in the Heap memory.

Example:

Consider writing a program that simulates a diving competition. The program will keep track of various athletes who perform dives. Assume that the following objects have been defined, each in their own files:

```java
public class Dive {
    String name;
    int difficulty;
}
```

```java
public class Performance {
    Dive dive;
    float[] scores;
}
```

```java
public class Athlete {
    String name;
    String country;
    Performance[] performances;
}
```

Notice that each Performance object contains a Dive object. That means, each performance corresponds to a single dive (i.e., an athlete performs one dive at a time). Also, you will notice that the Athlete keeps an array of Performance objects. That is, as the athlete performs dives over time, new performances will be added to this array … each performance representing a particular dive.

In order to make sure that we understand how objects are stored inside of one another, let us see if we can write code that constructs a particular arrangement of these objects. Here is a diagram showing the arrangement of objects that we would like to construct. Try to write the code that will produce this picture.
Looking at the picture, there are 3 *Athlete* objects, 6 *Performance* objects and 4 *Dive* objects. The remaining objects are Strings and arrays. Since the *Dive* objects don't contain the other objects that we created (i.e., neither *Athlete* nor *Performance*) we should start by making those first. We can store them into variables `d1`, `d2`, `d3` and `d4` for later use.

```java
Dive d1, d2, d3, d4;

d1 = new Dive();
d1.name = "reverse pike";
d1.difficulty = 3;

d2 = new Dive();
d2.name = "cannon ball";
d2.difficulty = 1;

d3 = new Dive();
d3.name = "reverse triple twist";
d3.difficulty = 4;

d4 = new Dive();
d4.name = "forward pike";
d4.difficulty = 2;
```
Now, we should create the Performance objects, making sure to point them to the correct Dive objects.

```
Performance p1, p2, p3, p4, p5, p6;
  p1 = new Performance();
  p1.dive = d1;
  p1.scores = new float[8];
  p2 = new Performance();
  p2.dive = d2;
  p2.scores = new float[8];
  p3 = new Performance();
  p3.dive = d3;
  p3.scores = new float[8];
  p4 = new Performance();
  p4.dive = d3;
  p4.scores = new float[8];
  p5 = new Performance();
  p5.dive = d4;
  p5.scores = new float[8];
  p6 = new Performance();
  p6.dive = d4;
  p6.scores = new float[8];
```

Finally, we create the Athlete objects:

```
Athlete art, dan, jen;
  art = new Athlete();
  art.name = "Art Class";
  art.country = "Canada";
  art.performances = new Performance[3];
  dan = new Athlete();
  dan.name = "Dan Druff";
  dan.country = "Germany";
  dan.performances = new Performance[3];
  jen = new Athlete();
  jen.name = "Jen Tull";
  jen.country = "U.S.A.";
  jen.performances = new Performance[3];
```

Of course, we need to simulate these athletes doing their performances. So we need to add the performances for each athlete:

```
  art.performances[0] = p1;
  art.performances[1] = p2;
  art.performances[2] = p3;
  dan.performances[0] = p4;
  dan.performances[1] = p5;
  jen.performances[0] = p6;
```

It seems like a lot of code, but we will see later how to shorten it. For now, it is just important that you understand how various objects are stored inside others.
As a further test of your understanding, see if you can write code to access and print out the following:

1. the difficulty level of Art's 2nd performance
2. the object representing Dan's 2nd performance
3. the 6th judge's score for Jen's first performance

Here are the solutions:

1. `System.out.println(art.performances[1].dive.difficulty);`
2. `System.out.println(dan.performances[1]);`
3. `System.out.println(jen.performances[0].scores[5]);`

Can you write code to determine the average judges' score for Art (consider all performances)? Assume that there are interesting scores stored in the data, because at the moment they are all 0.

```java
float sum = 0;

for(int p=0; p<3; p++) {
    for(int s=0; s<8; s++) {
        sum = sum + art.performances[p].scores[s];
    }
}
System.out.println(sum/24);
```

Do you understand this now? If not, you may want to come for further help during office hours. It is VERY important that you understand how to do this stuff.