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Preface

Like all Schaum's Outline Series books, this volume is intended to be used primarily for self study, preferably in conjunction with a regular course in data structures. However, it is also well-suited for use in independent study or as a reference.

The book includes over 200 examples and solved problems. I firmly believe that the principles of data structures can be learned from a well-constructed collection of examples with complete explanations. This book is designed to provide that support.

Source code for all the examples and problems in this book can be downloaded either from my website at `http://projectEuclid.net/schaums/dswj/` or from its mirror site at `http://www.richmond.edu/~hubbard/schaums/dswj/`. Any corrections or addenda for the book will also be available at these sites.

I wish to thank all my friends, colleagues, students, and the McGraw-Hill staff who have helped me with the critical review of this manuscript. Special thanks to my wife and colleague, Anita H. Hubbard, for her advice, encouragement, and creative ideas for this book. Many of the original problems used here are hers.

JOHN R. HUBBARD
Richmond, Virginia

JOHN R. HUBBARD is Professor of Mathematics and Computer Science at the University of Richmond. He received his Ph.D. from the University of Michigan in 1973 and has been a member of the Richmond faculty since 1983. His primary interests are in numerical algorithms and database systems. Dr. Hubbard's other *Schaum's Outline* books include *Programming with C++*, *Programming with Java*, *Fundamentals of Computing with C++*, and *Data Structures with C++*.

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Chapter 1

Review of Java

This chapter outlines those features of the Java programming language that are essential to the design and implementation of data structures. For more details, see the book **[Hubbard]** listed in Appendix D on page 362.

1.1 OBJECT-ORIENTED PROGRAMMING

Java is an *object-oriented* programming language:

- Every data item is encapsulated in some object.
- Every executable statement is performed by some object.
- Every object is an instantiation of some class or is an array.
- Every class is defined within a single inheritance hierarchy.

Java's single inheritance hierarchy is a tree structure whose root is the `Object` class. (See Section 3.4 on page 58.) This single structure might seem to render Java a simple language. However, that structure includes the Java 1.3 Class Libraries, which contain 2,130 classes with 23,901 members.

Object orientation makes Java particularly well-suited for the design and implementation of data structures. Its Collections Framework (see Chapter 4) provides an excellent platform for the programmer to construct data structures.

1.2 THE JAVA PROGRAMMING LANGUAGE

A *Java program* is a collection of one or more text files, at least one of which contains a unique `public` class with a unique method whose signature is

```
public static void main(String[] args)
```

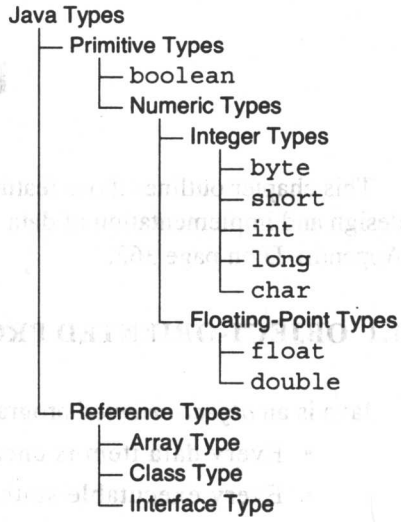
Each file in the program must contain a unique `public` class or `public` interface. Each file is named *X*`.java`, where *X* is the name of its unique `public` class or `public` interface. Each file *X*`.java` is compiled into a corresponding class file named *X*`.class`. Then the program is run by executing the *X*`.class` file that contains the `main(String[])` method that in turn contains the statements to be executed. This programming can be done from the command line or from within an IDE. (See Appendix C.)

1.3 VARIABLES AND OBJECTS

In any programming language, data are accessed through variables. In Java, a variable is either a reference to an object or one of the eight primitive types, as shown in the diagram at the top of the next page. If it is a reference, then its value is either `null` or it contains the address of an instantiated object.

Each object belongs to a unique class. The class defines its objects' properties and operations, just as a primitive type defines its variables' properties and operations.

A variable is created by a declaration that specifies its type and optional initial value. An object is created by the new operator invoking its class constructor.



EXAMPLE 1.1 Creating Variables and Objects

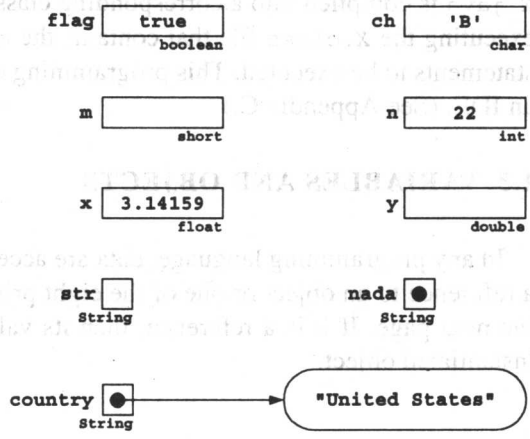
```
public class Ex0101
{ public static void main(String[] args)
  { boolean flag=true;
    char ch='B';
    short m;
    int n=22;
    float x=3.14159F;
    double y;
    String str;
    String nada=null;
    String country = new String("United States");
    System.out.println("flag = " + flag);
    System.out.println("ch = " + ch);
    System.out.println("n = " + n);
    System.out.println("x = " + x);
    System.out.println("nada = " + nada);
    System.out.println("country = " + country);
  }
}
```

```
flag = true
ch = B
n = 22
x = 3.14159
nada = null
country = United States
```

This program declares nine variables and then prints the six that were initialized. The first six variables are primitive types. The last three variables are references to String objects.

The program contains only one object: the String object named country. (Technically, country is the name of the variable that refers to the String object.)

The picture here shows the nine variables and the one object. Each variable has a name and a type. If the type is a class, then the variable is a reference to an instance (i.e., an object) of that class. The uninitialized variables appear empty; the others contain their values. The only possible value of a



reference variable is a reference, drawn as a black dot. If the reference is not `null`, then the dot has an arrow pointing to the object to which it refers. In Java, an object cannot exist unless some reference variable refers to it.

1.4 PRIMITIVE TYPES

Java defines eight primitive types:

`boolean` either `false` or `true`

`char` 16-bit Unicode character; e.g., `'B'` or `'π'`

`byte` 8-bit integer: `-128` to `127`

`short` 16-bit integer: `-32768` to `32767`

`int` 32-bit integer: `-2147483648` to `2147483647`

`long` 64-bit integer: `-9223372036854775808` to `9223372036854775807`

`float` 32-bit floating-point decimal: (plus or minus) `1.4E-45F` to `3.4E38F`

`double` 64-bit floating-point decimal: (plus or minus) `4.9E-324` to `1.8E308`

Note that `float` literals require an `F` suffix to distinguish them from values of type `double`.

Every Unicode character literal can be expressed in the form `'\uxxxx'`, where x is any hexadecimal digit. For example, `'B'` is `'\u0042'`, and `'π'` is `'\u03C0'`.

In addition to their numeric values, floating-point variables can also have any of the three special values `NEGATIVE_INFINITY`, `POSITIVE_INFINITY`, and `NaN` (for "not a number"). These special values result from improper arithmetic operations.

EXAMPLE 1.2 Special Values for Floating-Point Types

```
public class Ex0102
{ public static void main(String[] args)
  { double x=1E200;  // x=10000...0 (1 followed by 200 zeros)
    System.out.println("x = " + x);
    System.out.println("x*x = " + x*x);
    System.out.println("(x*x)/x = " + (x*x)/x);
    System.out.println("(x*x)/(x*x) = " + (x*x)/(x*x));
  }
}
x = 1.0E200
x*x = Infinity
(x*x)/x = Infinity
(x*x)/(x*x) = NaN
```

The value of `x*x` is `Infinity` because $(10^{200})(10^{200}) == 10^{400}$, which is greater than the maximum value $1.3(10^{308})$ for `double` type.

Algebraically, $(xx)/x = x$, but not so when x is infinite: `Infinity` divided by any nonnegative finite value will still be `Infinity`.

Finally, `Infinity` divided `Infinity` is not even infinite; it is algebraically indeterminate, so its Java value is `NaN`.

For each of the eight primitive types, Java defines a *wrapper class* that provides object-oriented services for manipulating primitive types. For example, the wrapper class for type `double` is `Double`, and the wrapper class for type `int` is `Integer`.

EXAMPLE 1.3 Using Wrapper Classes

```
public class Ex0103
{ public static void main(String[] args)
  { String s = "2.7182818284590";
    System.out.println("s = " + s);
    Double x = new Double(s);
    System.out.println("x = " + x);
    double y = x.doubleValue();
    System.out.println("y = " + y);
    s += 45;
    System.out.println("s = " + s);
    y += 45;
    System.out.println("y = " + y);
    int n = x.intValue();
    System.out.println("n = " + n);
    n = Integer.parseInt("3A9",16);
    System.out.println("n = " + n);
  }
}
```

```
s = 2.7182818284590
x = 2.718281828459
y = 2.718281828459
s = 2.718281828459045
y = 47.718281828459
n = 2
n = 937
```

The constructor `Double(s)` creates the `Double` object `x` from the `String` object `s`, storing the numeric value 2.7182818284590 inside the object `x`. The second `println()` statement implicitly invokes the `Double.toString()` method, which converts that numeric value back into a string to be printed. The `x.doubleValue()` invocation returns the stored numeric value that is assigned to `y`. Then the `+=` operator is applied to `String` object `s` and to the double variable `y`, with very different results. For strings, "+=" means "append to," but for numbers, it means "add to."

Next, the `Double.intValue()` method truncates that stored numeric value to the integer 2 and initializes `n` with it. Finally, `Integer.parseInt("3A9",16)` returns the `int` value (in decimal form) for the integer whose hexadecimal representation is `3A9`. That is $3(16^2) + 10(16) + 9 = 937$.

Note that the `+` operator automatically converts the number `y` into its string equivalent when combined with a string, as in the call `System.out.println("y = " + y)`.

1.5 FLOW CONTROL

Java supports the `if` statement, the `if..else` statement, the `switch` statement, and the *conditional expression operator* `?..:`.

EXAMPLE 1.4 Using Conditional Statements

This program generates random integers in the range 0 to 99 and then uses conditional statements to classify them.

```
public class Ex0104
{ public static void main(String[] args)
  { int n = (int)Math.round(100*Math.random());
    System.out.println("n = " + n);
```

```
    if (n>25 && n<75) System.out.println(n + " is between 25 and 75");
    else System.out.println(n + " is not between 25 and 75");
    switch ((int)n/20)
    { case  0: System.out.println(n + " < 20");
      case  1: System.out.println(n + " < 40");
      case  2: System.out.println(n + " < 60");  break;
      case  3: System.out.println(n + " < 80");  break;
      default: System.out.println(n + " >= 80");
    }
    System.out.println(n + (n%2>0 ? " is odd" : " is even"));
  }
}
n = 19
19 is not between 25 and 75
19 < 20
19 < 40
19 < 60
19 is odd
```

Note how the absence of the `break` statement in `case 0` and `case 1` allows control to "fall through" each of those cases on to `case 2`, executing all three of those `println()` statements.

The expression `(n%2>0 ? " is odd" : " is even")` evaluates to the string `" is odd"` if the condition `n%2>0` is true (i.e., `n` is not divisible by 2); otherwise it evaluates to the string `" is even"` (when `n` is divisible by 2).

Java supports the `while` statement, the `do..while` statement, and the `for` statement.

EXAMPLE 1.5 Using Loops

This program empirically tests Gauss's Prime Number Theorem: if $p(n)$ is the number of prime numbers that are less than n, then the ratio $p(n)(\ln n)/n$ approaches 1.0 as n grows without bound. It counts the number `p(n)` of prime numbers for each odd `n` in the range 3 to 1,000,000. As $p(n)$ increases, each time it passes a multiple of 5,000, the program prints the values of n, $p(n)$, $\ln n$ (the natural logarithm) and the ratio $p(n)(\ln n)/n$, which gets close to 1.0.

```
public class Ex0105
{ public static void main(String[] args)
  { System.out.println("n\tp(n)\tln(n)\t\t\tp(n)*ln(n)/n");
    final String DASHES18="\t------------------";
    System.out.println("------\t-----" + DASHES18 + DASHES18);
    int p=1;  // p = number of primes that are <= n
    for (int n=3; n<1000000; n += 2)
    { int d=3;
      while (d<=Math.sqrt(n) && n%d>0)
        d += 2;
      if (n%d==0) continue;
      ++p;
      if (p%5000>0) continue;
      double ln=Math.log(n);
      System.out.println(n + "\t" + p + "\t" + ln + "\t" + p*ln/n);
    }
    System.out.println("------\t-----" + DASHES18 + DASHES18);
  }
}
```