Boolean Expressions and Conditions

The physical order of a program is the order in which the statements are listed. The logical order of a program is the order in which the statements are executed. With conditional structures and control structures that we will examine soon, it is possible to change the order in which statements are executed.

Boolean Data Type

To ask a question in a program, you make a statement. If your statement is true, the answer to the question is yes. If your statement is not true, the answer to the question is no. You make these statements in the form of Boolean expressions. A Boolean expression asserts (states) that something is true. The assertion is evaluated and if it is true, the Boolean expression is true. If the assertion is not true, the Boolean expression is false.

In Java, data type boolean is used to represent Boolean data. Each boolean constant or variable can contain one of two values: true or false.

Relational Operators

A Boolean expression can be a simple Boolean variable or constant or a more complex expression involving one or more of the relational operators. Relational operators take two operands and test for a relationship between them. The following table shows the relational operators and the Java symbols that stand for them.

<table>
<thead>
<tr>
<th>Java Symbol</th>
<th>Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>==</td>
<td>Equal to (not =)</td>
</tr>
<tr>
<td>!=</td>
<td>Not equal to (since no key for ≠)</td>
</tr>
<tr>
<td>&gt;</td>
<td>Greater than</td>
</tr>
<tr>
<td>&lt;</td>
<td>Less than</td>
</tr>
<tr>
<td>&gt;=</td>
<td>Greater than or equal to</td>
</tr>
<tr>
<td>&lt;=</td>
<td>Less than or equal to</td>
</tr>
</tbody>
</table>

For example, the Boolean expression

number1 < number2
evaluates to `true` if the value stored in `number1` is less than the value stored in `number2`, and evaluated to `false` otherwise.

Examples:

```java
boolean b;
b = 3 < 1;
System.out.println(b);  // Outputs “false”
b = 3 > 1;
System.out.println(b);  // Outputs “true”
```

When a relational operator is applied between variables of type `char`, the assertion is in terms of where the two operands fall in the collating sequence of a particular character set. For example,

```java
char character1, character2;
character1 = 'a';
character2 = 'b';
```

```
boolean b;
b = 'a' < 'b';
System.out.println(b);  // Outputs “true”, ASCII a = 96, b = 97
b = 'a' < 'B';
System.out.println(b);  // Outputs “false”, ASCII a = 96, B=66
```

We must be careful when applying the relational operators to floating point operands, particularly equal (==) and not equal (!=). Integer values can be represented exactly; floating point values with fractional parts often are not exact in the low-order decimal places. Therefore, you should compare floating point values for near equality. For now, do *not* compare floating point numbers for equality.

For example consider the program below:

```java
class NumberTest {
    public static void main(String[] argv) throws Exception {
        float f = 1111111111f;
        f = f + 1;
        System.out.println(f);
    }
}
```
The output is:

1.11111117E9

This is the same as 1111111117, not the expected 1111111112 that is the correct value. This is due to roundoff errors with the IEEE 754 floating point format. In any case, this shows that if we compare for exact equality with an expected floating point value, we may not get a match (i.e., compare \( f == 1111111112 \)). But if we compare for a data range, then we should be ok.

### Boolean Operators

A simple Boolean expression is either a Boolean variable or constant or an expression involving the relational operators that evaluates to either true or false. These simple Boolean expressions can be combined using the logical operations defined on Boolean values. There are three Boolean operators: AND, OR, and NOT. Here is a table showing the meaning of these operators and the symbols that are used to represent them in Java.

<table>
<thead>
<tr>
<th>Java Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>&amp;&amp;</td>
<td>AND is a binary Boolean operator. If both operands are true, the result is true. Otherwise, the result is false.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>!</td>
<td>NOT is a unary Boolean operator. NOT changes the value of its operand: If the operand is true, the result is false; if the operand is false, the result is true.</td>
</tr>
</tbody>
</table>
If relational operators and Boolean operators are combined in the same expression in Java, the Boolean operator NOT (!) has the highest precedence, the relational operators have next higher precedence, and the Boolean operators AND (&&) and OR (||) come last (in that order). Expressions in parentheses are always evaluated first.

For example, given the following expression (stop is a bool variable)

```
    count <= 10 && sum >= limit || !stop
```

!stop is evaluated first, the expressions involving the relational operators are evaluated next, the && is applied, and finally the || is applied. Java uses short-circuit evaluation. The evaluation is done in left-to-right order and halts as soon as the result is known. For example, in the above expression if both of the arithmetic expressions are true, the evaluation stops because the left operand to the OR operation (|| operator) is true. There is no reason to evaluate the rest of the expression: true OR anything is true. Short-circuit evaluation raises some subtleties that experienced programmers can take advantage of.

It is a good idea to use parenthesis to make your expressions more readable, e.g:

```
    (((count <=10) && (sum>=limit))  ||  (!stop))
```

This also helps avoid difficult-to-find errors if the programmer forgets the precedence rules.

The following table summarizes the precedence of some of the common Java operators:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Type</th>
<th>Order of Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(  )</td>
<td>Parentheses</td>
<td>left to right</td>
</tr>
<tr>
<td>[  ]</td>
<td>Array subscript</td>
<td>left to right</td>
</tr>
<tr>
<td>.</td>
<td>Member access</td>
<td>right to left</td>
</tr>
<tr>
<td>++ --</td>
<td>Prefix increment, decrement</td>
<td>right to left</td>
</tr>
<tr>
<td>++ --</td>
<td>Postfix increment, decrement</td>
<td>right to left</td>
</tr>
<tr>
<td>* / %</td>
<td>Multiplicative</td>
<td>left to right</td>
</tr>
<tr>
<td>+ -</td>
<td>Additive</td>
<td>left to right</td>
</tr>
<tr>
<td>&lt; &gt; &lt;= &gt;=</td>
<td>Relational</td>
<td>left to right</td>
</tr>
<tr>
<td>== !=</td>
<td>Equality</td>
<td>left to right</td>
</tr>
<tr>
<td>&amp;&amp;</td>
<td>And</td>
<td>left to right</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>? :</td>
<td>Conditional</td>
<td>right to left</td>
</tr>
<tr>
<td>= += -= *= /= %=</td>
<td>Assignment</td>
<td>right to left</td>
</tr>
</tbody>
</table>
If-Then and If-Then-Else Statements

The If statement allows the programmer to change the logical order of a program; that is, make the order in which the statements are executed differ from the order in which they are listed in the program. The If-Then statement uses a Boolean expression to determine whether to execute a statement or to skip it. The format is as follows:

```java
if (boolean_expression)
    statement;
```

The statement will be executed if the Boolean expression is true. If you wish to execute multiple statements, which is called a block, use curly braces:

```java
if (boolean_expression) {
    statement1;
    statement2;
    ...
    statement99;
}
```

Although the curly braces are not needed when only a single statement is executed, some programmers always use curly braces to help avoid errors such as:

```java
if (boolean_expression)
    statement1;
    statement2;
```

This is really the same as:

```java
if (boolean_expression)
    statement1;
    statement2;
```

Such a condition commonly arises when initially only a single statement is desired, and then a programmer goes back and adds additional statements, forgetting to add curly braces.

We can also add an optional else or else if clause to an if statement. The else statement will be executed if all above statements are false. Use else if to test for multiple conditions:
if (boolean_expression1)
    statement1; // Expr1 true
else if (boolean_expression2)
    statement2; // Expr1 false, Expr2 true
else if (boolean_expression3)
    statement3; // Expr1, Expr2 false, Expr3 true
...
else
    statement_all_above_failed; // Expr1, Expr2, Expr3 false

Here are some examples of if statements:

```java
if (number < 0)
    number = 0;
sum = sum + number;
```

```
if (number < 0) {
    number = 0;
}
sum = sum + number;
```

```
if (number < 0) {
    number = 0;
    sum = sum + number;
}
```

In all of these examples, the expression \((\text{number} < 0)\) is evaluated. If the result is true, the statement \(\text{number} = 0\) is executed. If the result is false, the statement is skipped. In the first two cases, the next statement to be executed is \(\text{sum} = \text{sum} + \text{number}\). In the last case, \(\text{sum} = \text{sum} = \text{number}\) is only evaluated if \(\text{number} < 0\).

Here is another example.

```java
System.out.println("Today is a ");
if (temperature <= 32)
    System.out.println("Cold day.");
    System.out.println("Sitting by the fire is appropriate.");
else
    System.out.println("nice day. How about taking a walk?");
```
There is a point of Java syntax that you should note: There is never a semicolon after the right brace of a block (compound statement).

Finally here is an example using else-if, also referred to as a **nested if statement**:

```java
if (y==false)
    if (z < 50) {
    } else {
        ...
    }
```

There may be confusion as to what the final else statement goes to. Does it match up with \( z < 50 \)? or with \( y == \text{false} \)? The rule is that the else is paired with the most recent if statement that does not have an else. In this case, the final else statement is paired with \( z < 50 \). The above is equivalent to:

```java
if (y==false) {
    if (z < 50) {
        ...
    } else {
        ...
    }
}
```

If we wanted the else to match up with \( y == \text{false} \), we should change the braces accordingly:

```java
if (y==false) {
    if (z<5) { ... }
} else {
    ...
}
```

In nested If statements, there may be confusion as to which if an else belongs. In the absence of braces, the compiler pairs an else with the most recent if that doesn't have an else. You can override this pairing by enclosing the preceding if in braces to make the then clause of the outer if statement complete.
**Compound Statements and Short Circuit**

We can use relational operators to make more complicated if-then statements. Consider the following:

```java
int i=0,j=2,k=4;
if (((k/j)<10) && ((k*j)<9)) {
    System.out.println("foo");
} else {
    System.out.println("bar");
}
```

This will evaluate 4/2 as being less than 10. Also 4*2 is less than 9. Consequently, “foo” should be printed.

Now consider the following:

```java
int i=0,j=2,k=4;
if (((k/j)<10) || ((k*j)<9)) {
    System.out.println("foo");
} else {
    System.out.println("bar");
}
```

“foo” will still be printed. However, since we have a logical OR this means that we only need one of the top expressions to be evaluated to true. Java works left to right, so once it finds that k/j < 10 is true, it skips the (k*j)<9 expression. This helps save processing time and also lets us have potentially “invalid” expressions:

```java
int i=0,j=2,k=4;
if (((k/i)<10) || ((k*j)<9)) {
    System.out.println("foo");
} else {
    System.out.println("bar");
}
```

This will crash, resulting in a division by 0 error.
However, what about the following:

```java
int i=0,j=2,k=4;
if (((k*j)<9) || ((k/i)<10)) {
    System.out.println("foo");
} else {
    System.out.println("bar");
}
```

or

```java
int i=0,j=2,k=4;
if (((k*j)>8) && ((k/i)<10)) {
    System.out.println("foo");
} else {
    System.out.println("bar");
}
```

The short-circuit behavior of Java allows us to avoid the fatal computations. This is useful in some cases when the “illegal” instructions are actually legal in the event that the first condition was true.

**Common Bug #1: Confusing = and ==**

The assignment operator (=) and the equality test operator (==) can easily be miskeyed one for the other. What happens if this occurs? Fortunately, the program will not compile. Look at the following statements.

```java
int i=0;
i == i + 1;
System.out.println(i);
```

This code fragment generates an error during compilation. i==i+1 will be flagged as an improper instruction.

Look at the next statement going the other direction:

```java
int i=0;
if (i=1) {
    System.out.println("Value is 1");
} else {
    System.out.println("Value is 0");
}
```
This code will also be flagged as an error by the compiler. \( i=1 \) does not return a Boolean, and we must make a Boolean comparison in the if-statement.

Fortunately, these common problems are discovered by the Java compiler. However, if you start to program in C or C++, these statements will not be flagged as errors by the compiler because they are valid statements. Unfortunately, they are probably not statements you wish to make and will likely result in a program that does not function correctly.

**Common Bug #2: Using == with Strings and Objects**

Fortunately, the compiler catches the previous bugs (unless the data types happen to be Boolean). Not so for the next common bug, using == with Strings. Although == correctly tests two values for primitive data types like numbers and chars, it has a different meaning when applied to objects.

First, let’s see how == works correctly on primitive data types. All variables are stored at some memory address. For variables of primitive data types, the value is stored directly in memory at that address. For example, say that we create two integers:

\[
\text{int } x=1, y=1;
\]

Let’s say that the compiler decides to place variable \( x \) at address 1000 and variable \( y \) at address 2000. A snapshot of memory looks something like this:

<table>
<thead>
<tr>
<th>Memory Address</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000:</td>
<td>…</td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
<td>1000:</td>
<td>1</td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
<td>2000:</td>
<td>1</td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
</tbody>
</table>

When Java executes \( x == y \), the == operator checks to see if the contents of memory corresponding to variables \( x \) and \( y \) are the same. In this case, we compare 1 from address 1000 with 1 from address 2000, they are identical, and Java correctly returns the boolean value true.

Objects such as strings are stored differently, resulting in a different behavior when we use ==. An object really occupies a number of bytes of memory. These bytes store data associated with the object (e.g., a string of characters). The variable that represents the object is really storing the **memory address** where the data is stored.
For example, say that we create a String object s1:

```java
String s1 = "hi", s2 = "hi";
```

The variable s1 is also stored somewhere in memory, let’s say at address 1000. The variable s2 is also stored somewhere, let’s say at address 2000. The contents of the two object variables contains the memory address of the place where we are putting the object. Let’s say we have “hi” for s1 stored at address 3000, and “hi” for s2 stored at address 4000:

<table>
<thead>
<tr>
<th>Memory Address</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000:</td>
<td>…</td>
</tr>
<tr>
<td>…</td>
<td></td>
</tr>
<tr>
<td>1000:</td>
<td>3000</td>
</tr>
<tr>
<td>…</td>
<td></td>
</tr>
<tr>
<td>2000:</td>
<td>4000</td>
</tr>
<tr>
<td>…</td>
<td></td>
</tr>
<tr>
<td>3000:</td>
<td>h</td>
</tr>
<tr>
<td>3002:</td>
<td>i</td>
</tr>
<tr>
<td>…</td>
<td></td>
</tr>
<tr>
<td>4000:</td>
<td>h</td>
</tr>
<tr>
<td>4002:</td>
<td>i</td>
</tr>
<tr>
<td>…</td>
<td></td>
</tr>
</tbody>
</table>

What happens now if we execute: `s1 == s2`? Java will do the same thing it did before: it compares the contents of s1 with the contents of s2. In this case, it is comparing 3000 with 4000. These are actually memory addresses, and they are different, so Java will return back the value false. In this case, the `==` operator isn’t smart enough to know that we actually want to go look at the data stored at the memory addresses and compare them instead.

Whenever we create variables for objects that actually store memory addresses, these variables are called **references** or **pointers**. Graphically, we can depict them a bit more conveniently using arrows and boxes:
Here is a program that illustrates the above problem (if you actually run the above, Java may store the “hi” in the same place and == may actually work):

```java
boolean b;
String s1,s2;
Scanner keyboard = new Scanner(System.in);

s1 = keyboard.nextLine();
s2 = keyboard.nextLine();

System.out.println("S1 = "+ s1);
System.out.println("S2 = "+ s2);
if (s1 == s2) System.out.println("Equal");
else System.out.println("Not equal");
```

Try running this program with the same input. Java will say they are not equal.

As one further example, consider the following change:

```java
boolean b;
String s1,s2;
Scanner keyboard = new Scanner(System.in);

s1 = keyboard.nextLine();
s2 = s1;

System.out.println("S1 = "+ s1);
System.out.println("S2 = "+ s2);
if (s1 == s2) System.out.println("Equal");
else System.out.println("Not equal");
```
Using our hypothetical values from earlier, we now have a picture that looks like:

![Memory Contents Diagram]

Both variables are now referring to the same location due to the assignment, so the program now prints out “Equal”. You might wonder why such behavior might be useful. This will become much more useful later on when we discuss linked data structures.

For now then, how do we compare strings to see if they are the same? We need to compare every character of each string to see if they match. Fortunately, there is already a string method defined that does this for us, called equals():

```java
s1 = keyboard.readLine();
s2 = keyboard.readLine();

System.out.println("S1 = " + s1);
System.out.println("S2 = " + s2);
if (s1.equals(s2)) System.out.println("Equal");
else System.out.println("Not equal");
```

There is also a method called equalsIgnoreCase() that checks for equality but treats upper and lower case the same.

There is also a method called compareTo() that compares two strings and returns a number based on lexicographic ordering (i.e. if one is alphabetically greater than or less than the other). This will be useful later when we do things like sort lists of names.

**Sample Exercises**

Given an integer n with some value, determine if the number n is even or odd.

Given three numbers, a, b, and c, with some values in them, copy the largest of all three numbers into the variable "biggest"

Given a string variable s with some data in it, print out "A" if the first letter is an 'a' or 'A' and "Not A" otherwise.