Chapter 5
Loops

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Chapter 5

Loops

Objectives

- To write programs for executing statements repeatedly using a while loop (§5.2).
- To follow the loop design strategy to develop loops (§§5.2.1–5.2.3).
- To control a loop with a sentinel value (§5.2.4).
- To obtain large input from a file using input redirection rather than typing from the keyboard (§5.2.5).
- To write loops using do-while statements (§5.3).
- To write loops using for statements (§5.4).
- To discover the similarities and differences of three types of loop statements (§5.5).
- To write nested loops (§5.6).
- To learn the techniques for minimizing numerical errors (§5.7).
- To learn loops from a variety of examples (GCD, FutureTuition, Dec2Hex) (§5.8).
- To implement program control with break and continue (§5.9).
5.1 Introduction 160

- Suppose that you need to print a string (e.g., "Welcome to Java!") a hundred times. It would be tedious to have to write the following statement a hundred times:

  System.out.println("Welcome to Java!");

  So, how do you solve this problem?

- Loops are structures that control repeated executions of a block of statements.
- Java provides a powerful control structure called a loop, which controls how many times an operation or a sequence of operation is performed in succession.
- Java provides three types of loop statements while loops, do-while loops, and for loops.

5.2 The while Loop 160

- The syntax for the while loop is as follows:

  while (loop-continuation-condition) {
      // loop-body
      Statement(s);
  }

  The braces enclosing a while loop or any other loop can be omitted only if the loop body contains one or no statement. The while loop flowchart is in Figure 5.1 (a).
- The loop-continuation-condition, a Boolean expression, must appear inside the parentheses. It is always evaluated before the loop body is executed.
- If its evaluation is true, the loop body is executed; if its evaluation is false, the entire loop terminates, and the program control turns to the statement that follows the while loop.
• For example, the following while loop prints Welcome to Java! 100 times.

```java
ing count = 0;
while (count < 100) {
    System.out.println("Welcome to Java!");
    count++;
}
```

![Diagram of the while loop](image)

**FIGURE 5.1** The while loop repeatedly executes the statements in the loop body when the loop-continuation-condition evaluates to true.

**Note**

• Make sure that the loop-continuation-condition eventually becomes false so that the program will terminate.
• A common programming error involves infinite loops.
5.3 Case Study: Guessing Numbers 163

- Write a program that randomly generates an integer **between 0 and 100, inclusive**. The program prompts the user to enter a number continuously until the number matches the randomly generated number. For each user input, the program tells the user whether the input is too low or too high, so the user can choose the next input intelligently.

**LISTING 5.3 GuessNumber.java**

```java
import java.util.Scanner;

public class GuessNumber {
    public static void main(String[] args) {
        // Generate a random number to be guessed
        int number = (int)(Math.random() * 101);

        Scanner input = new Scanner(System.in);
        System.out.println("Guess a magic number between 0 and 100");

        int guess = -1;
        while (guess != number) {
            // Prompt the user to guess the number
            System.out.print("Enter your guess: ");
            guess = input.nextInt();

            if (guess == number)
                System.out.println("Yes, the number is " + number);
            else if (guess > number)
                System.out.println("Your guess is too high");
            else
                System.out.println("Your guess is too low");
        } // End of loop
    }
}
```

Guess a magic number between 0 and 100

Enter your guess: 50
Your guess is too high

Enter your guess: 25
Your guess is too high

Enter your guess: 12
Your guess is too high

Enter your guess: 6
Your guess is too low

Enter your guess: 9
Yes, the number is 9
5.4 Loop Design Strategies

- The Math subtraction learning tool program generates just one question for each run. You can use a loop to generate questions repeatedly. This example gives a program that generates five questions and reports the number of the correct answers after a student answers all five questions.

LISTING 5.4 SubtractionQuizLoop.java

```java
import java.util.Scanner;

public class SubtractionQuizLoop {
    public static void main(String[] args) {
        final int NUMBER_OFQUESTIONS = 5; // Number of questions
        int correctCount = 0; // Count the number of correct answers
        int count = 0; // Count the number of questions
        long startTime = System.currentTimeMillis();
        String output = ""; // output string is initially empty
        Scanner input = new Scanner(System.in);

        while (count < NUMBER_OFQUESTIONS) {
            // 1. Generate two random single-digit integers
            int number1 = (int)(Math.random() * 10);
            int number2 = (int)(Math.random() * 10);

            // 2. If number1 < number2, swap number1 with number2
            if (number1 < number2) {
                int temp = number1;
                number1 = number2;
                number2 = temp;
            }

            // 3. Prompt the student to answer "What is number1 - number2?"
            System.out.print("What is "+ number1 + " - "+ number2 + "? ");
            int answer = input.nextInt();

            // 4. Grade the answer and display the result
            if (number1 - number2 == answer) {
                System.out.println("You are correct!");
                correctCount++;
            } else
                System.out.println("Your answer is wrong.\n"+ number1 + " - " + number2 + " should be " + (number1 - number2));

            // Increase the count
            count++;

            output += "\n" + number1 + "-" + number2 + "=" + answer + ((number1 - number2 == answer) ? " correct" : " wrong")
        }
    }
}
```
long endTime = System.currentTimeMillis();
long testTime = endTime - startTime;

System.out.println("Correct count is " + correctCount +
   "\nTest time is " + testTime / 1000 + " seconds\n" + output);
}

What is 9 - 2? 7
Your answer is correct!

What is 3 - 0? 3
Your answer is correct!

What is 3 - 2? 1
Your answer is correct!

What is 7 - 4? 4
Your answer is wrong.
7 - 4 should be 3

What is 7 - 5? 4
Your answer is wrong.
7 - 5 should be 2

Correct count is 3
Test time is 1021 seconds

9-2=7 correct
3-0=3 correct
3-2=1 correct
7-4=4 wrong
7-5=4 wrong
5.5 Controlling a Loop with User Confirmation or a Sentinel Value

- Often the number of times a loop is executed is not predetermined. You may use an input value to signify the end of the loop. Such a value is known as a sentinel value.
- Write a program that reads and calculates the sum of an unspecified number of integers. The input 0 signifies the end of the input.

LISTING 5.5 SentinelValue.java

```java
import java.util.Scanner;

public class SentinelValue {
    /** Main method */
    public static void main(String[] args) {
        // Create a Scanner
        Scanner input = new Scanner(System.in);

        // Read an initial data
        System.out.print(
            "Enter an int value (the program exits if the input is 0): ");
        int data = input.nextInt();

        // Keep reading data until the input is 0
        int sum = 0;
        while (data != 0) {
            sum += data;

            // Read the next data
            System.out.print(
                "Enter an int value (the program exits if the input is 0): ");
            data = input.nextInt();
        }

        System.out.println("The sum is " + sum);
    }
}
```

- If data is not 0, it is added to the sum and the next input data are read. If data is 0, the loop body is not executed and the while loop terminates.
- If the first input read is 0, the loop body never executes, and the resulting sum is 0.
- The do-while loop executes the loop body first, and then checks the loop-continuation condition to determine whether to continue or terminate the loop.
Caution

- **Don’t** use floating-point values for **equality** checking in a loop control. Since floating-point values are **approximations** for some values, using them could result in imprecise counter values and inaccurate results. Consider the following code for computing \(1 + 0.9 + 0.8 + \ldots + 0.1\):

```java
double item = 1; double sum = 0;
while (item != 0) { // No guarantee item will be 0
    sum += item;
    item -= 0.1;
}
System.out.println(sum);
```

- Variable item starts with 1 and is reduced by 0.1 every time the loop body is executed. The loop should terminate when item becomes 0. However, there is no guarantee that item will be **exactly 0**, because the floating-point arithmetic is **approximated**. This loop seems OK on the surface, but it is actually an **infinite** loop.

Input and Output Redirections

- If you have a large number of data to enter, it would be cumbersome to type from the keyboard. You may store the data separated by whitespaces in a text file, say input.txt, and run the program using the following command:

  ```java
  java SentinelValue < input.txt
  ```

- This command is called **input redirection**. The program takes the input from the file input.txt rather than having the user to type the data from the keyboard at runtime.

- There is **output redirection** which sends the output to a file rather than displaying it on the console. The command for output redirection is:

  ```java
  java ClassName > output.txt
  ```

- Input and output redirection can be used in the same command. For example, the following command gets input from input.txt and sends output to output.txt:

  ```java
  java SentinelValue < input.txt > output.txt
  ```
5.6 The do-while Loop 171

- The do-while is a variation of the while-loop. Its syntax is shown below.

```java
do {
    // Loop body
    Statement(s);
}
while (continue-condition); // Do not forget ";"
```

![Flowchart](image)

**FIGURE 5.2** The do-while loop executes the loop body first, then checks the loop-continuation-condition to determine whether to continue or terminate the loop.

- The loop body is **executed first**. Then the loop-continuation-condition is evaluated.
- If the evaluation is true, the loop body is executed **again**; if it is false, the do-while loop terminates.
- The major difference between a while loop and a do-while loop is the **order** in which the loop-continuation-condition is evaluated and the loop body is executed.
- The while loop and the do-while loop have equal expressive power.
- Sometimes one is a more convenient choice than the other.
- **Tip**: Use the do-while loop if you have statements inside the loop that must be executed **at least once**.
• You can rewrite the TestWhile program shown previously as follows:

**LISTING 5.6 TestDoWhile.java**

```java
import java.util.Scanner;

class TestDoWhile {
    public static void main(String[] args) {
        int data;
        int sum = 0;

        Scanner input = new Scanner(System.in);

        do {
            System.out.print("Enter an int value (the program exits if the input is 0): ");
            data = input.nextInt();
            sum += data;
        } while (data != 0);

        System.out.println("The sum is "+ sum);
    }
}
```

Enter an int value (the program exits if the input is 0): 2
Enter an int value (the program exits if the input is 0): 3
Enter an int value (the program exits if the input is 0): 4
Enter an int value (the program exits if the input is 0): 0
The sum is 9
5.7 The for Loop 173

- The syntax of a for loop is as shown below.

```java
for (initial-action; loop-continuation-condition; action-after-each-iteration) {
    // loop body;
    Statement(s);
}
```

- The for loop statement starts with the keyword `for`, followed by a pair of parentheses enclosing `initial-action`, `loop-continuation-condition`, and `action-after-each-iteration`, and the loop body, enclosed inside braces.

- `initial-action`, `loop-continuation-condition`, and `action-after-each-iteration` are separated by semicolons;

- A `for` loop generally uses a variable to control how many times the loop body is executed and when the loop terminates.

- This variable is referred to as a control variable. The `initial-action` often initializes a control variable, the `action-after-each-iteration` usually increments or decrements the control variable, and the `loop-continuation-condition` tests whether the control variable has reached a termination value.

- A for loop can be used to avoid the potential error and simplify the preceding loop as shown in (a) below. In general, the syntax for a for loop is as shown in (a), which is equivalent to (b).

```
for (i = initialValue; i < endValue; i++) {
    // Loop body
    ... 
}
```

```
i = initialValue;
while (i < endValue) {
    // Loop body
    ... 
i++;
}
```
Example: The following for loop prints Welcome to Java! 100 times.

```java
int i;
for (i = 0; i < 100; i++) {
    System.out.println("Welcome to Java!");
}
```

![Diagram of for loop execution](a)

![Diagram of for loop execution](b)

**FIGURE 5.3** A for loop performs an initial action one, then repeatedly executes the statements in the loop body, and performs an action after an iteration when the loop-continuation-condition evaluates as true.

- The for loop initializes `i` to 0, then repeatedly executes the `println` and evaluates `i++` if `i` is less than 100.
- The initial-action, `i = 0`, initializes the control variable, `i`.
- The loop-continuation-condition, `i < 100`, is a Boolean expression.
- The expression is evaluated at the beginning of each iteration.
- If the condition is `true`, execute the loop body. If it is `false`, the loop terminates and the program control turns to the line following the loop.
- The action-after-each-iteration, `i++`, is a statement that adjusts the control variable.
- This statement is executed after each iteration. It increments the control variable.
- Eventually, the value of the control variable forces the loop-continuation-condition to become `false`. 
The loop control variable can be declared and initialized in the for loop as follows:

```java
for (int i = 0; i < 100; i++) {
    System.out.println("Welcome to Java");
}
```

**Note**

- The **initial-action** in a for loop can be a list of zero or more comma-separated variable declaration statements or assignment expressions.

```java
for (int i = 0, j = 0; (i + j < 10); i++, j++) {
    // Do something
}
```

- The **action-after-each-iteration** in a for loop can be a list of zero or more comma-separated statements. The following is correct but not a good example, because it makes the code hard to read.

```java
for (int i = 1; i < 100; System.out.println(i), i++);
```

**Note**

- If the **loop-continuation-condition** in a for loop is omitted, it is implicitly true. Thus, the statement given below in (a), which is an infinite loop, is the same as in (b). To avoid confusion, though, it is better to use the equivalent loop in (c).

```
for (; ; ) {
    // Do something
}
```

(_Equivalent_)

```
for (; true; ) {
    // Do something
}
```

(_Equivalent_)

```
while (true) {
    // Do something
}
```

(_This is better_)

(a) \hspace{2cm} (b) \hspace{2cm} (c)
5.8 Which Loop to Use? 176

- The three forms of loop statements, `while`, `do`, and `for`, are expressively equivalent; that is, you can write a loop in any of these three forms.
- For example, a `while` loop in (a) in the following figure can always be converted into the following `for` loop in (b):

\[
\text{while (loop-continuation-condition) } \\
\{ \\
// Loop body \\
\}
\]

\[
\text{for (; loop-continuation-condition; ) } \\
\{ \\
// Loop body \\
\}
\]

- A `for` loop in (a) in the following figure can generally be converted into the following while loop in (b) except in certain special cases.

\[
\text{for (initial-action; } \\
\text{loop-continuation-condition; } \\
\text{action-after-each-iteration) } \\
\{ \\
// Loop body; \\
\}
\]

\[
\text{while (loop-continuation-condition) } \\
\{ \\
// Loop body; \\
\text{action-after-each-iteration; }
\}
\]

Recommendations

- The author recommends that you use the one that is most intuitive and comfortable for you.
- In general, a `for` loop may be used if the number of repetitions is known, as, for example, when you need to print a message 100 times.
- A `while` loop may be used if the number of repetitions is not known, as in the case of reading the numbers until the input is 0.
- A `do-while` loop can be used to replace a `while` loop if the loop body has to be executed before testing the continuation condition.
Caution

- Adding a semicolon at the end of the for clause before the loop body is a common mistake, as shown below in (a). In (a), the semicolon signifies the end of the loop prematurely. The loop body is actually empty, as shown in (b). (a) and (b) are equivalent. Both are incorrect.

![Diagram](a)

![Diagram](b)

- Similarly, the loop in (c) is also wrong. (c) is equivalent to (d). Both are incorrect.

![Diagram](c)

![Diagram](d)

- In the case of the do-while loop, the **semicolon** is needed to end the loop.

![Diagram](This is correct.)
5.9 Nested Loops 178

- Nested loops consist of an outer loop and one or more inner loops. Each time the outer loop is repeated, the inner loops are reentered, and all the required iterations are performed.

- Problem: Write a program that uses nested for loops to print a multiplication table.

LISTING 5.7 MultiplicationTable.java

```java
public class MultiplicationTable {
    /** Main method */
    public static void main(String[] args) {
        // Display the table heading
        System.out.println("           Multiplication Table");

        // Display the number title
        System.out.print("    ");
        for (int j = 1; j <= 9; j++)
            System.out.print("   "+j);
        System.out.println("\n-----------------------------------------");

        // Print table body
        for (int i = 1; i <= 9; i++) {
            System.out.print(i + " | ");
            for (int j = 1; j <= 9; j++) {
                // Display the product and align properly
                System.out.printf("%4d", i * j);
            }
            System.out.println();
        }
    }
}
```

```
<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
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<td>18</td>
<td>27</td>
<td>36</td>
<td>45</td>
<td>54</td>
<td>63</td>
<td>72</td>
<td>81</td>
</tr>
</tbody>
</table>
```
5.10 Minimizing Numeric Errors 180

- Numeric errors involving floating-point numbers are inevitable.

- Write a program that sums a series that starts with 0.01 and ends with 1.0. The numbers in the series will increment by 0.01, as follows 0.01 + 0.02 + 0.03 and so on.

**LISTING 5.8 TestSum.java**

```java
public class TestSum {
    public static void main(String[] args) {
        // Initialize sum
        float sum = 0;

        // Add 0.01, 0.02, ..., 0.99, 1 to sum
        for (float i = 0.01f; i <= 1.0f; i = i + 0.01f)
            sum += i;

        // Display result
        System.out.println("The sum is " + sum);
    }
}
```

The sum is 50.499985

- The for loop repeatedly adds the control variable i to the sum. This variable, which begins with 0.01, is incremented by 0.01 after each iteration. The loop terminates when i exceeds 1.0.

- The exact sum should be **50.50**, but the answer is **50.499985**. The result is not precise because computers use a fixed number of bits to represent floating-point numbers, and thus cannot represent some floating-point number exactly.

- If you change float in the program to **double** as follows, you should see a slight improvement in precision because a double variable takes 64 bits, whereas a float variable takes 32 bits.

```java
public class TestSum {
    public static void main(String[] args) {
        // Initialize sum
        double sum = 0;

        // Add 0.01, 0.02, ..., 0.99, 1 to sum
        for (double i = 0.01; i <= 1.0; i = i + 0.01)
            sum += i;

        // Display result
        System.out.println("The sum is " + sum);
    }
}
```

The sum is 49.50000000000003

The sum is 49.50000000000003
To fix the problem: Using an **integer count** to ensure that all the numbers are processed.

```java
public class TestSum {
    public static void main(String[] args) {
        // Initialize sum
        double sum = 0;
        double currentValue = 0.01;

        // Add 0.01, 0.02, ..., 0.99, 1 to sum
        for (int count = 0; count < 100; count++) {
            sum += currentValue;
            currentValue += 0.01;
        }

        // Display result
        System.out.println("The sum is " + sum);
    }
}
```

The sum is **50.50000000000003**
5.11 Case Studies 182

- Control statements are fundamental in programming.
- The ability to write control statement is essential in learning Java programming.
- *If you can write programs using loops, you know how to program!*

5.11.1 Case Study: Finding the Greatest Common Divisor

- **Problem:** Write a program that prompts the user to enter two positive integers and finds their greatest common divisor.
- **Solution:** Suppose you enter two integers 4 and 2, their greatest common divisor is 2. Suppose you enter two integers 16 and 24, their greatest common divisor is 8. So, how do you find the greatest common divisor? Let the two input integers be n1 and n2. You know number 1 is a common divisor, but it may not be the greatest common divisor. So, you can check whether k (for k = 2, 3, 4, and so on) is a common divisor for n1 and n2, until k is greater than n1 or n2.

LISTING 5.9 GreatestCommonDivisor.java

```java
import java.util.Scanner;

public class GreatestCommonDivisor {
    /** Main method */
    public static void main(String[] args) {
        // Create a Scanner
        Scanner input = new Scanner(System.in);

        // Prompt the user to enter two integers
        System.out.print("Enter first integer: ");
        int n1 = input.nextInt();
        System.out.print("Enter second integer: ");
        int n2 = input.nextInt();

        int gcd = 1;
        int k = 2;
        while (k <= n1 && k <= n2) {
            if (n1 % k == 0 && n2 % k == 0) {
                gcd = k;
                k++;
            }
        }

        System.out.println("The greatest common divisor for " + n1 + " and " + n2 + " is " + gcd);
    }
}
```

Enter first integer: 125
Enter second integer: 2525
The greatest common divisor for 125 and 2525 is 25
5.11.2 Case Study: Predicating the Future Tuition

- Problem: Suppose that the tuition for a university is $10,000 this year and tuition increases 7% every year. In how many years will the tuition be doubled?

```
double tuition = 10000; // Year 0
int year = 0;
tuition = tuition * 1.07; year++; // Year 1
tuition = tuition * 1.07; year++; // Year 2
tuition = tuition * 1.07; year++; // Year 3
...
```

LISTING 5.10 FutureTuition.java

```java
public class FutureTuition {
    public static void main(String[] args) {
        double tuition = 10000; // Year 0
        int year = 0;
        while (tuition < 20000) {
            tuition = tuition * 1.07;
            year++;
        }
        System.out.println("Tuition will be doubled in "+ year + " years");
        System.out.printf("Tuition will be %.2f in %d years",
            tuition, year);
    }
}
```

Tuition will be doubled in 11 years
Tuition will be $21048.52 in 11 years
5.12 Keywords break and continue 186

- The **break** control *immediately ends the innermost loop* that contains it. It is generally used with an *if* statement.
- The **continue** control *only ends the current iteration*. Program control goes to the end of the loop body. This keyword is generally used with an *if* statement.
- The **break** statement forces its containing loop to exit.

- The **continue** statement forces the current iteration of the loop to end.
Demonstrating a break Statement

LISTING 5.12 TestBreak.java

- This program adds the integers from 1 to 20 in this order to sum until sum is greater than or equal to 100.
  
  Output:
  - The number is 14
  - The sum is 105

- Without the if statement, the program calculates the sum of the numbers from 1 to 20.
  
  Output:
  - The number is 20
  - The sum is 210

```java
public class TestBreak {
    public static void main(String[] args) {
        int sum = 0;
        int number = 0;
        
        while (number < 20) {
            number++;
            sum += number;
            if (sum >= 100) break;
        }
        
        System.out.println("The number is " + number);
        System.out.println("The sum is " + sum);
    }
}
```

The number is 14
The sum is 105
Demonstrating a continue Statement

LISTING 5.13 TestContinue.java

- This program adds all the integers from 1 to 20 except 10 and 11 to sum.

  Output:
  The sum is 189

- Without the if statement in the program, all of the numbers are added to sum, even when number is 10 or 11.

  Output:
  The sum is 210

```java
public class TestContinue {
    public static void main(String[] args) {
        int sum = 0;
        int number = 0;

        while (number < 20) {
            number++;
            if (number == 10 || number == 11) continue;
            sum += number;
        }

        System.out.println("The sum is "+sum);
    }
}
```

The sum is 189