Chapter 5: Loops and Iteration

Motivations
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:

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

So, how do you solve this problem?

Opening Problem

Problem:

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

Introducing while Loops

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

- To write programs for executing statements repeatedly using a while loop (§5.2).
- 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).
- To write a program that displays prime numbers (§5.11).

while Loop Flow Chart

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

Trace while Loop

```java
int count = 0;
while (count < 2) {
    System.out.println("Welcome to Java!");
    count++;
}
```
int count = 0;
while (count < 2) {
    System.out.println("Welcome to Java!");
count++;
}

(count < 2) is still true since count is 1

Print Welcome to Java

Increase count by 1
count is 1 now

Print Welcome to Java
Trace while Loop, cont.

```java
int count = 0;
while (count < 2) {
    System.out.println("Welcome to Java!");
    count++;
}
```

Increase count by 1
Count is 2 now

(count < 2) is false since count is 2 now

The loop exits. Execute the next statement after the loop.

Problem: Repeat Addition Until Correct

Recall that Listing 3.1 AdditionQuiz.java gives a program that prompts the user to enter an answer for a question on addition of two single digits. Using a loop, you can now rewrite the program to let the user enter a new answer until it is correct.
Problem: Guessing Numbers
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. Here is a sample run:

Problem: An Advanced Math Learning Tool
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.

Ending a Loop with 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.

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 + ... + 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);
```
do-while Loop

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

for Loops

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

Trace for Loop

int i;
for (i = 0; i < 2; i++) {
    System.out.println(“Welcome to Java!”);
}

Trace for Loop, cont.

int i;
for (i = 0; i < 2; i++) {
    System.out.println(“Welcome to Java!”);
}
int i;
for (i = 0; i < 2; i++) {
    System.out.println("Welcome to Java!");
}

(i < 2) is true since i is 0

int i;
for (i = 0; i < 2; i++) {
    System.out.println("Welcome to Java!");
}

(i < 2) is true since i is 0

int i;
for (i = 0; i < 2; i++) {
    System.out.println("Welcome to Java!");
}

(i < 2) is still true since i is 1
int i;
for (i = 0; i < 2; 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 expressions. The action-after-each-iteration in a for loop can be a list of zero or more comma-separated statements. Therefore, the following two for loops are correct. They are rarely used in practice, however.

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

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

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 correct. Nevertheless, it is better to use the equivalent loop in (b) to avoid confusion:

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

```java
(b) Equivalent while (true) {
    // Do something
}
```

Caution

Adding a semicolon at the end of the for clause before the loop body is a common mistake, as shown below:

```java
Logic Error
for (int i = 0; i < 10; i++);
{
    System.out.println("i is " + i);
}
```

Caution, cont.

Similarly, the following loop is also wrong:

```java
Logic Error
int i = 0;
while (i < 10);
{
    System.out.println("i is " + i);
    i++;
}
```

In the case of the do loop, the following semicolon is needed to end the loop.

```java
Logic Error
int i = 0;
do {
    System.out.println("i is " + i);
    i++;
} while (i < 10);
```

Correct
Which Loop to Use?

The three forms of loop statements, while, do-while, 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):

```
while (loop-continuation-condition) {
    // Loop body;
}
```

Equivalent
```
for (initial-action; loop-continuation-condition; action-after-each-iteration) {
    // 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 (see Review Question 3.19 for one of them):

```
for ( ; loop-continuation-condition; action-after-each-iteration) {
    // Loop body;
}
```

Equivalent
```
while (loop-continuation-condition) {
    // Loop body;
    action-after-each-iteration;
}
```

Recommendations

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.

Nested Loops

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

Minimizing Numerical Errors

Numeric errors involving floating-point numbers are inevitable. This section discusses how to minimize such errors through an example.

Here is an example 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.
Problem: 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.

Problem: Predicting 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?

Problem: Predicating the Future Tuition

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

Case Study: Converting Decimals to Hexadecimals

Hexadecimals are often used in computer systems programming (see Appendix F for an introduction to number systems). How do you convert a decimal number to a hexadecimal number? To convert a decimal number d to a hexadecimal number is to find the hexadecimal digits $h_0, h_1, h_2, ..., h_n, h_1, and h_0$ such that

$$d = h_0 \cdot 16^0 + h_1 \cdot 16^1 + h_2 \cdot 16^2 + ... + h_n \cdot 16^n$$

These hexadecimal digits can be found by successively dividing d by 16 until the quotient is 0. The remainders are $h_0, h_1, h_2, ..., h_n, h_1, and h_0$. 
Problem: Monte Carlo Simulation

The Monte Carlo simulation refers to a technique that uses random numbers and probability to solve problems. This method has a wide range of applications in computational mathematics, physics, chemistry, and finance. This section gives an example of using the Monte Carlo simulation for estimating $\pi$.

\[
\frac{\text{circleArea}}{\text{squareArea}} = \frac{\pi}{4}.
\]

$\pi$ can be approximated as

\[
\frac{\text{numberOfHits}}{\text{numberOfTrials}}.
\]

Using break and continue

Examples for using the `break` and `continue` keywords:

- TestBreak.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);  
    }  
}
```

- TestContinue.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);  
    }  
}
```
Guessing Number Problem Revisited

Here is a program for guessing a number. You can rewrite it using a `break` statement.

Problem: Checking Palindrome

A string is a palindrome if it reads the same forward and backward. The words “mom,” “dad,” and “noon,” for instance, are all palindromes.

The problem is to write a program that prompts the user to enter a string and reports whether the string is a palindrome. One solution is to check whether the first character in the string is the same as the last character. If so, check whether the second character is the same as the second-to-last character. This process continues until a mismatch is found or all the characters in the string are checked, except for the middle character if the string has an odd number of characters.

Problem: Displaying Prime Numbers

Problem: Write a program that displays the first 50 prime numbers in five lines, each of which contains 10 numbers. An integer greater than 1 is prime if its only positive divisor is 1 or itself. For example, 2, 3, 5, and 7 are prime numbers, but 4, 6, 8, and 9 are not.

Solution: The problem can be broken into the following tasks:
• For number = 2, 3, 4, 5, 6, ..., test whether the number is prime.
• Determine whether a given number is prime.
• Count the prime numbers.
• Print each prime number, and print 10 numbers per line.

Debugging Loops in IDE Tools

Supplements II.C, II.E, and II.G.