Building Java Programs

Chapter 5:
Program Logic and Indefinite Loops

Lecture outline

Lecture 11

- **indefinite loops**
  - **the `while` loop**
  - **sentinel loops**

Lecture 12

- generating random numbers with `Random` objects
- Boolean logic
  - `boolean` expressions and variables
  - logical operators
- testing for valid user input

Lecture 13

- indefinite loop variations
  - the `do/while` loop
- logical assertions

while loops

- suggested reading: 5.1

Definite loops

- **definite loop**: One that executes a known number of times.
  - The `for` loops we have seen so far are definite loops.
  - We often use language like,
    - "Repeat these statements *N* times."
    - "For each of these 10 things, ..."
  - Examples:
    - Print "hello" 10 times.
    - Find all the prime numbers up to an integer *n*.
    - Print each odd number between 5 and 127.

Indefinite loops

- **indefinite loop**: One where it is not obvious in advance how many times it will execute.
  - The `while` loops in this chapter are indefinite loops.
  - We often use language like,
    - "Keep looping *as long as* or *while* this condition is still true."
    - "Don't stop repeating *until* the following happens."
  - Examples:
    - Prompt the user until they type a non-negative number.
    - Print random numbers until a prime number is printed.
    - Continue looping while the user has not typed "n" to quit.

The while loop statement

- **while loop**: Executes a group of statements as long as a condition is true.
  - well suited to writing indefinite loops
- The while loop, general syntax:

```
while (<condition>) {
    <statement(s)> ;
}
```

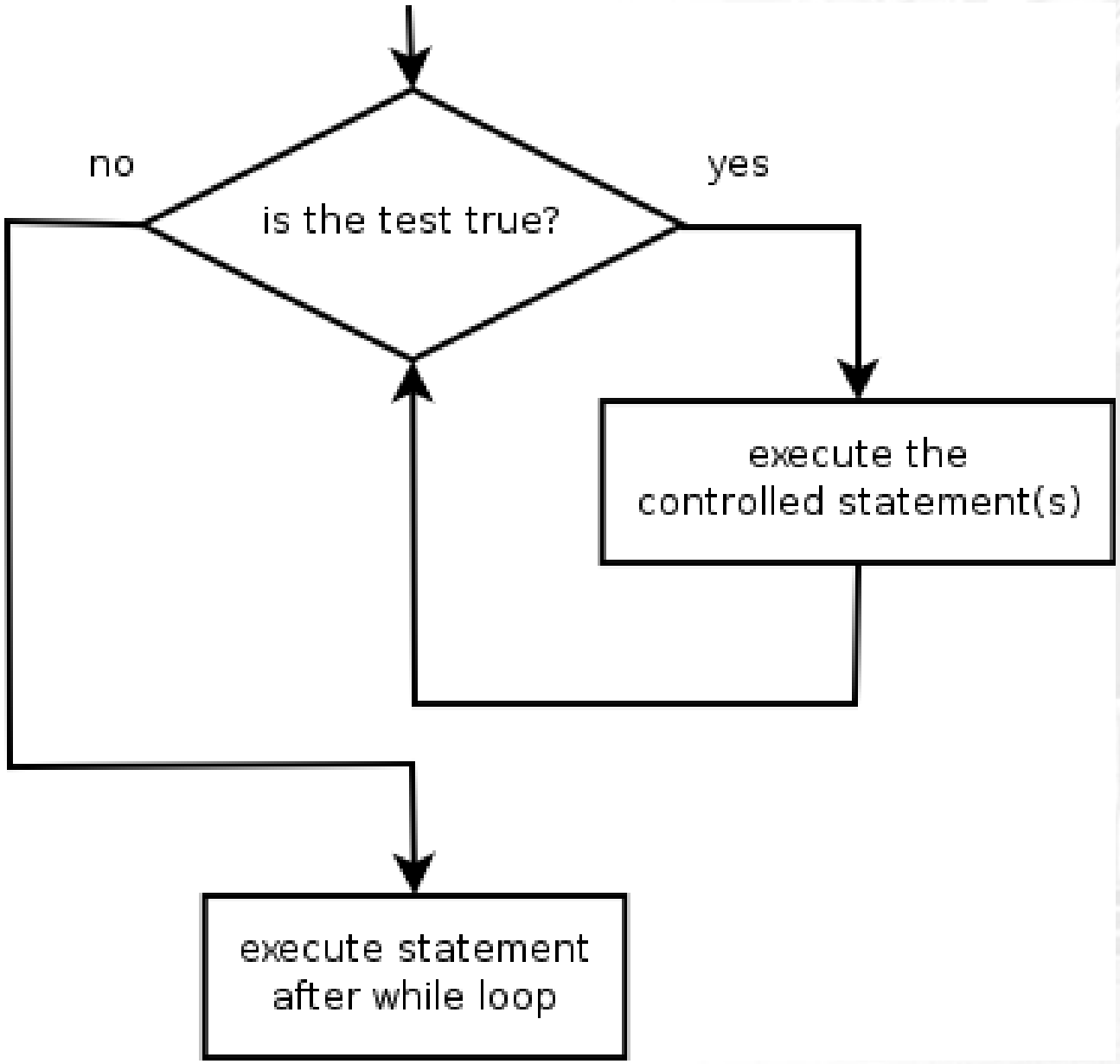
- Example:

```
int number = 1;
while (number <= 200) {
    System.out.print(number + " ");
    number *= 2;
}
```

  - OUTPUT:

```
1 2 4 8 16 32 64 128
```

While loop flow chart



Example while loop

- Finds and prints a number's first factor other than 1:

```
Scanner console = new Scanner(System.in);
System.out.print("Type a number: ");
int number = console.nextInt();
int factor = 2;
while (number % factor != 0) {
    factor++;
}
System.out.println("First factor: " + factor);
```

- Example log of execution:

```
Type a number: 91
First factor: 7
```

Equivalence of for,while loops

- Any `for` loop of the following form:

```
for (<initialization>; <condition>; <update>) {
    <statement(s)>;
}
```

can be replaced by a `while` loop of the following form:

```
<initialization>;
while (<condition>) {
    <statement(s)>;
    <update>;
}
```

for/while loop example

- What `while` loop is essentially equivalent to the following `for` loop?

```
for (int i = 1; i <= 10; i++) {
    System.out.println(i + " squared = " + (i * i));
}
```

- ANSWER:

```
int i = 1;
while (i <= 10) {
    System.out.println(i + " squared = " + (i * i));
    i++;
}
```

While loop problem

- Write a piece of Java code that uses a `while` loop to repeatedly prompt the user to type a number until the user types a non-negative number, then square it.
  - Example log of execution:

```
Type a non-negative integer: -5
Invalid number, try again: -1
Invalid number, try again: -235
Invalid number, try again: -87
Invalid number, try again: 11
11 squared is 121
```

While loop solution

- Solution:

```
System.out.print("Type a non-negative integer: ");
int number = console.nextInt();

while (number < 0) {
    System.out.print("Invalid number, try again: ");
    number = console.nextInt();
}

int square = number * number;
System.out.println(number + " squared is " + square);
```

  - Notice that the `int number` has to be declared outside the while loop in order to remain in scope.

While loop question

- Write a method named `digitSum` that accepts an integer as a parameter and returns the sum of the digits of that number.
  - `digitSum(29107)` returns `2+9+1+0+7` or `19`
  - You may assume that the number is non-negative.
  - Hint: Use the `%` operator to extract the last digit of a number.
    - If we do this repeatedly, when should we stop?

While loop answer

- The following code implements the method:

```
public static int digitSum(int n) {
    int sum = 0;
    while (n > 0) {
        sum += n % 10;   // add last digit to sum
        n = n / 10;      // remove last digit
    }
    return sum;
}
```

Sentinel loops

- suggested reading: 5.1

Sentinel values

- **sentinel**: A special input value that signals the end of the user's input.
- **sentinel loop**: Repeats until a sentinel value is seen.
  - Example: Write a program that repeatedly prompts the user for numbers to add until the user types 0, then outputs their sum.

    (In this case, 0 is our sentinel value.)

  - Example log of execution:

```
Enter a number (0 to quit): 95
Enter a number (0 to quit): 87
Enter a number (0 to quit): 42
Enter a number (0 to quit): 26
Enter a number (0 to quit): 0
The total was 250
```

Flawed sentinel solution

- What's wrong with this solution?

```
Scanner console = new Scanner(System.in);
int sum = 0;
int inputNumber = 1;   // "dummy value", anything but 0

while (inputNumber != 0) {
    System.out.print("Enter a number (0 to quit): ");
    inputNumber = console.nextInt();
    sum += inputNumber;
}

System.out.println("The total was " + sum);
```

A different sentinel value

- Modify your program to use a sentinel value of **-1**.
  - Example log of execution:

```
Enter a number (-1 to quit): 95
Enter a number (-1 to quit): 87
Enter a number (-1 to quit): 42
Enter a number (-1 to quit): 26
Enter a number (-1 to quit): -1
The total was 250
```

Changing the sentinel value

- To see the problem, change the sentinel's value to -1:

```
Scanner console = new Scanner(System.in);
int sum = 0;
int inputNumber = 1;  // "dummy value", anything but -1

while (inputNumber != -1) {
    System.out.print("Enter a number (-1 to quit): ");
    inputNumber = console.nextInt();
    sum += inputNumber;
}

System.out.println("The total was " + sum);
```

- Now the solution produces the wrong output. Why?

```
The total was 249
```

The problem with our code

- Our code uses a pattern like this:

  sum = 0.

  while input is not the sentinel:

  prompt for input; read input.

  add input to the sum.

- On the last pass through the loop, the sentinel value -1 is added to the sum:

  prompt for input; read input (-1).

  add input (-1) to the sum.

- This is a fencepost problem.
  - We want to read *N* numbers (*N* is not known ahead of time), but only sum the first *N* - 1 of them.

A fencepost solution

- We need the code to use a pattern like this:

sum = 0.
prompt for input; read input.

while input is not the sentinel:
    add input to the sum.
    prompt for input; read input.

- Sentinel loops often utilize a fencepost-style "loop-and-a-half" solution by pulling some code out of the loop.

More correct code

- This solution produces the correct output:

```
Scanner console = new Scanner(System.in);
int sum = 0;
System.out.print("Enter a number (-1 to quit): ");
int inputNumber = console.nextInt();

while (inputNumber != -1) {
    sum += inputNumber;      // moved to top of loop
    System.out.print("Enter a number (-1 to quit): ");
    inputNumber = console.nextInt();
}

System.out.println("The total was " + sum);
```

Even better code

- An even better solution creates a constant for the sentinel:

```
public static final int SENTINEL = -1;
```

- This solution uses the constant:

```
Scanner console = new Scanner(System.in);
int sum = 0;
System.out.print("Enter a number (" + SENTINEL + " to quit): ");
int inputNumber = console.nextInt();

while (inputNumber != SENTINEL) {
    sum += inputNumber;

    System.out.print("Enter a number (" + SENTINEL + " to quit): ");
    inputNumber = console.nextInt();
}

System.out.println("The total was " + sum);
```

Generating random numbers

- suggested reading: 5.1

The Random class

- Java has a class named `Random` whose objects generate pseudo-random numbers.
  - Class `Random` is found in the `java.util` package.

```
import java.util.*;
```

Method name	Description
`nextInt()`	returns a random integer
`nextInt(`*max*`)`	returns a random integer in the range [0, *max*) in other words, from 0 through one less than *max*
`nextDouble()`	returns a random real number in the range [0.0, 1.0)

  - Example:

```
Random rand = new Random();
int randomNumber = rand.nextInt(10);
// randomNumber has a random value between 0 and 9
```

Generating random numbers

- Common usage: to get a random number from 1 to *N*
  - Example: A random integer between 1 and 20, inclusive:

```
int n = rand.nextInt(20) + 1;
```

- To get a number in arbitrary range [*min*, max]:

  `nextInt(`***<size of the range>***`) + ***<min>***`

  where ***<size of the range>*** equals ***<max>*** - ***<min>*** + 1

  - Example: A random integer between 5 and 10 inclusive:

```
int n = rand.nextInt(6) + 5;
```

Random questions

- Given the following declaration, how would you get:

```
Random rand = new Random();
```

  - A random number between 0 and 100 inclusive?

  - A random number between 1 and 100 inclusive?

  - A random number between 4 and 17 inclusive?

Random answers

- Given the following declaration, how would you get:

```
Random rand = new Random();
```

  - A random number between 0 and 100 inclusive?

```
int random1 = rand.nextInt(101);
```

  - A random number between 1 and 100 inclusive?

```
int random1 = rand.nextInt(101) + 1;
```

  - A random number between 4 and 17 inclusive?

```
int random1 = rand.nextInt(14) + 4;
```

Random question

- Write a program that simulates rolling of two six-sided dice until their combined result comes up as 7.
  - Example log of execution:

```
Roll: 2 + 4 = 6
Roll: 3 + 5 = 8
Roll: 5 + 6 = 11
Roll: 1 + 1 = 2
Roll: 4 + 3 = 7
You won after 5 tries!
```

Random/while question

- Write a multiplication tutor program. Example log of execution:

```
This program helps you practice multiplication
by asking you random multiplication questions
with numbers ranging from 1 to 20
and counting how many you solve correctly.

14 * 8 = 112
Correct!
5 * 12 = 60
Correct!
8 * 3 = 24
Correct!
5 * 5 = 25
Correct!
20 * 14 = 280
Correct!
19 * 14 = 256
Incorrect; the correct answer was 266
You solved 5 correctly.
```

  - Use a class constant for the maximum value of 20.

Random/while answer

```
import java.util.*;

// Asks the user to do multiplication problems and scores them.
public class MultTutor {
    public static final int MAX = 20;

    public static void main(String[] args) {
        introduction();
        Scanner console = new Scanner(System.in);

        // loop until user gets one wrong
        int correct = 0;
        while (askQuestion(console)) {
            correct++;
        }

        System.out.println("You solved " + correct + " correctly.");
    }

    public static void introduction() {
        System.out.println("This program helps you practice multiplication");
        System.out.println("by asking you random multiplication questions");
        System.out.println("with numbers ranging from 1 to " + MAX);
        System.out.println("and counting how many you solve correctly.");
        System.out.println();
    }

    ...
```

Random/while answer 2

```
    ...

    public static boolean askQuestion(Scanner console) {
        // pick two random numbers between 1 and 20 inclusive
        Random rand = new Random();
        int num1 = rand.nextInt(MAX) + 1;
        int num2 = rand.nextInt(MAX) + 1;

        System.out.print(num1 + " * " + num2 + " = ");
        int guess = console.nextInt();
        if (guess == num1 * num2) {
            System.out.println("Correct!");
            return true;
        } else {
            System.out.println("Incorrect; the correct answer was " +
                               (num1 * num2));
            return false;
        }
    }
}
```

Random text and others

- `Random` can be used in text processing.
  - Code to pick a random lowercase letter:

```
char letter = (char) ('a' + rand.nextInt(26));
```

  - Code to pick a random character from a string (in this case, a random vowel):

```
String vowels = "aeiou";
char vow = vowels.charAt(rand.nextInt(vowels.length()));
```

  - Another example: code to pick a random letter representing a base in a DNA strand (A, C, G, or T):

```
String bases = "ACGT";
char base = bases.charAt(rand.nextInt(bases.length()));
```

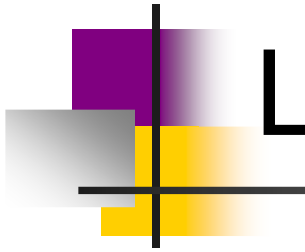
Other random values

- `Random` can be used with `double`
  - `nextDouble` method returns a `double` between 0.0 and 1.0
  - To get a double in a different range, multiply and/or add
  - Example: Gets a random value between 1.5 and 4.0:

```
double randomGpa = rand.nextDouble() * 2.5 + 1.0;
```

- `Random` can be used to pick between arbitrary choices
  - Code to pick a red, green, or blue color:

```
int r = rand.nextInt(3);
if (r == 0) {
    g.setColor(Color.RED);
} else if (r == 1) {
    g.setColor(Color.GREEN);
} else {
    g.setColor(Color.BLUE);
}
```



Lecture outline

Lecture 11

- indefinite loops
  - the `while` loop
  - sentinel loops

Lecture 12

- **generating random numbers with `Random` objects**
- **Boolean logic**
  - **`boolean` expressions and variables**
  - **logical operators**
- **testing for valid user input**

Lecture 13

- indefinite loop variations
  - the `do/while` loop
- logical assertions

Boolean logic

- suggested reading: 5.2

Type boolean

- **`boolean`**: A primitive type to represent logical values.
  - A `boolean` expression produces either `true` or `false`.
  - The ***<condition>***s in `if` statements, `for` loops are `boolean`.

  - Examples:

```
boolean minor = (age < 21);
boolean expensive = (ps3Price > 500.00);
boolean iLoveCS = true;

if (minor) {
    System.out.println("Can't purchase alcohol!");
}
```

  - You can create `boolean` variables, pass `boolean` parameters, return `boolean` values from methods, ...

Logical operators && || !

- Boolean expressions can use *logical operators*:

Operator	Description	Example	Result
&&	and	`(9 != 6) && (2 < 3)`	`true`
||	or	`(2 == 3) || (-1 < 5)`	`true`
!	not	`!(7 > 0)`	`false`

- Truth tables of each operator used with `boolean` values p and q:

p	q	p && q	p || q
`true`	`true`	`true`	`true`
`true`	`false`	`false`	`true`
`false`	`true`	`false`	`true`
`false`	`false`	`false`	`false`

p	!p
`true`	`false`
`false`	`true`

Boolean logic questions

- What is the result of each of the following expressions?

```
int x = 42;
int y = 17;
int z = 25;
```

  - `y < x && y <= z`
  - `x % 2 == y % 2 || x % 2 == z % 2`
  - `x <= y + z && x >= y + z`
  - `!(x < y && x < z)`
  - `(x + y) % 2 == 0 || !((z - y) % 2 == 0)`

- Answers: `true`, `false`, `true`, `true`, `false`

Methods that return boolean

- There are methods in Java that return `boolean` values.
  - A call to one of these methods can be used as a ***<condition>*** in a `for` loop, `while` loop, or `if` statement.

  - Examples:

```
Scanner console = new Scanner(System.in);
System.out.print("Type your name: ");
String line = console.nextLine();

if (line.startsWith("Dr.")) {
    System.out.println("Will you marry me?");
} else if (line.endsWith(", Esq.")) {
    System.out.println("And I am Ted 'Theodore' Logan!");
}
```

String boolean methods

- The following `String` methods return `boolean` values:

Method	Description
`equals(`*`String`*`)`	whether two strings contain exactly the same characters
`equalsIgnoreCase(`*`String`*`)`	whether two strings contain the same characters, ignoring upper vs. lower case differences
`startsWith(`*`String`*`)`	whether one string contains the other's characters at its start
`endsWith(`*`String`*`)`	whether one string contains the other's characters at its end

String boolean examples

```
Scanner console = new Scanner(System.in);
System.out.print("Type your full name and title: ");
String name = console.nextLine();

if (name.endsWith("Ph. D.")) {
    System.out.println("Hello, doctor!");
}
if (name.startsWith("Ms.")) {
    System.out.println("Greetings, Ma'am.");
}
if (name.equalsIgnoreCase("boss")) {
    System.out.println("Welcome, master!  Command me!");
}
if (name.toLowerCase().indexOf("jr.") >= 0) {
    System.out.println("Your parent has the same name!");
}
```

Writing boolean methods

- Methods can return a `boolean` result.

```
public static boolean isLowerCaseLetter(char ch) {
    if ('a' <= ch && ch <= 'z') {
        return true;
    } else {
        return false;
    }
}
```

- Calls to such methods can be used as conditions:

```
String name = "e.e. cummings";
char firstLetter = name.charAt(0);
if (isLowerCaseLetter(firstLetter)) {
    System.out.println("You forgot to capitalize your name!");
}
```

"Boolean Zen"

- Methods that return a boolean result often have an `if/else` statement:

```
public static boolean isLowerCaseLetter(char ch) {
    if ('a' <= ch && ch <= 'z') {
        return true;
    } else {
        return false;
    }
}
```

- ... but the `if/else` is sometimes unnecessary.
  - The `if/else`'s condition is itself a `boolean` expression; its value is exactly the value you want to return.
  - So just return it directly!

```
public static boolean isLowerCaseLetter(char c) {
    return ('a' <= c && c <= 'z');
}
```

Boolean practice problems

- Write a method named `isVowel` that returns whether a particular character is a vowel (a, e, i, o, or u). Count only lowercase vowels.
  - `isVowel('q')` returns `false`
  - `isVowel('e')` returns `true`
- Write a method named `allDigitsOdd` that returns whether every digit of an integer is an odd number.
  - `allDigitsOdd(19351)` returns `true`
  - `allDigitsOdd(234)` returns `false`
- Write a method named `countVowels` that returns the number of lowercase vowels in a `String`.
  - `countVowels("Marty Stepp")` returns 2
  - `countVowels("e pluribus unum")` returns 6

Boolean practice problem

- Write a program that compares two words typed by the user to see whether they "*rhyme*" (end with the same last two letters) and/or *alliterate* (begin with the same letter).
  - Use methods with return values to tell whether two words rhyme and/or alliterate.
  - Example logs of execution:

```
(run #1)
Type two words: car STAR
They rhyme!

(run #2)
Type two words: bare bear
They alliterate!

(run #3)
Type two words: sell shell
They alliterate!
They rhyme!
```

Boolean practice problem

- Write a program that reads a number from the user and tells whether it is prime, and if not, gives the next prime after it.
  - Example logs of execution: (run #1)

```
Type a number: 29
29 is prime
```

```
(run #2)
Type two numbers: 14
14 is not prime; the next prime after 14 is 17
```

- As part of your solution, write two methods:
  - `isPrime`: Returns `true` if the parameter passed is a prime number
  - `nextPrime`: Returns the next prime number whose value is greater than or equal to the parameter passed. (If the parameter passed is prime, returns that number.)

Boolean practice problem

- Modify your program from the previous slide so that it reads two numbers and tells whether each is prime, or if not, gives the next prime after it; also tell whether they are *relatively prime* (have no common factors).
  - Example logs of execution: (run #1)

```
Type two numbers: 9 16
9 is not prime; the next prime after 9 is 11
16 is not prime; the next prime after 16 is 17
9 and 16 are relatively prime
```

(run #2)

```
Type two numbers: 7 21
7 is prime
21 is not prime; the next prime after 21 is 23
7 and 21 are not relatively prime
```

Lecture outline

Lecture 11

- indefinite loops
  - the `while` loop
  - sentinel loops

Lecture 12

- generating random numbers with `Random` objects
- Boolean logic
  - `boolean` expressions and variables
  - logical operators
- testing for valid user input

Lecture 13

- **indefinite loop variations**
  - **the `do/while` loop**
- **logical assertions**

Indefinite loop variations

- suggested reading: 5.4

The do/while loop

- **do/while loop**: Executes statements repeatedly while a condition is true, testing it at the end of each repetition.
  - Similar to a `while` loop, except that its body statement(s) will always execute the first time, regardless of whether the condition is true or false.

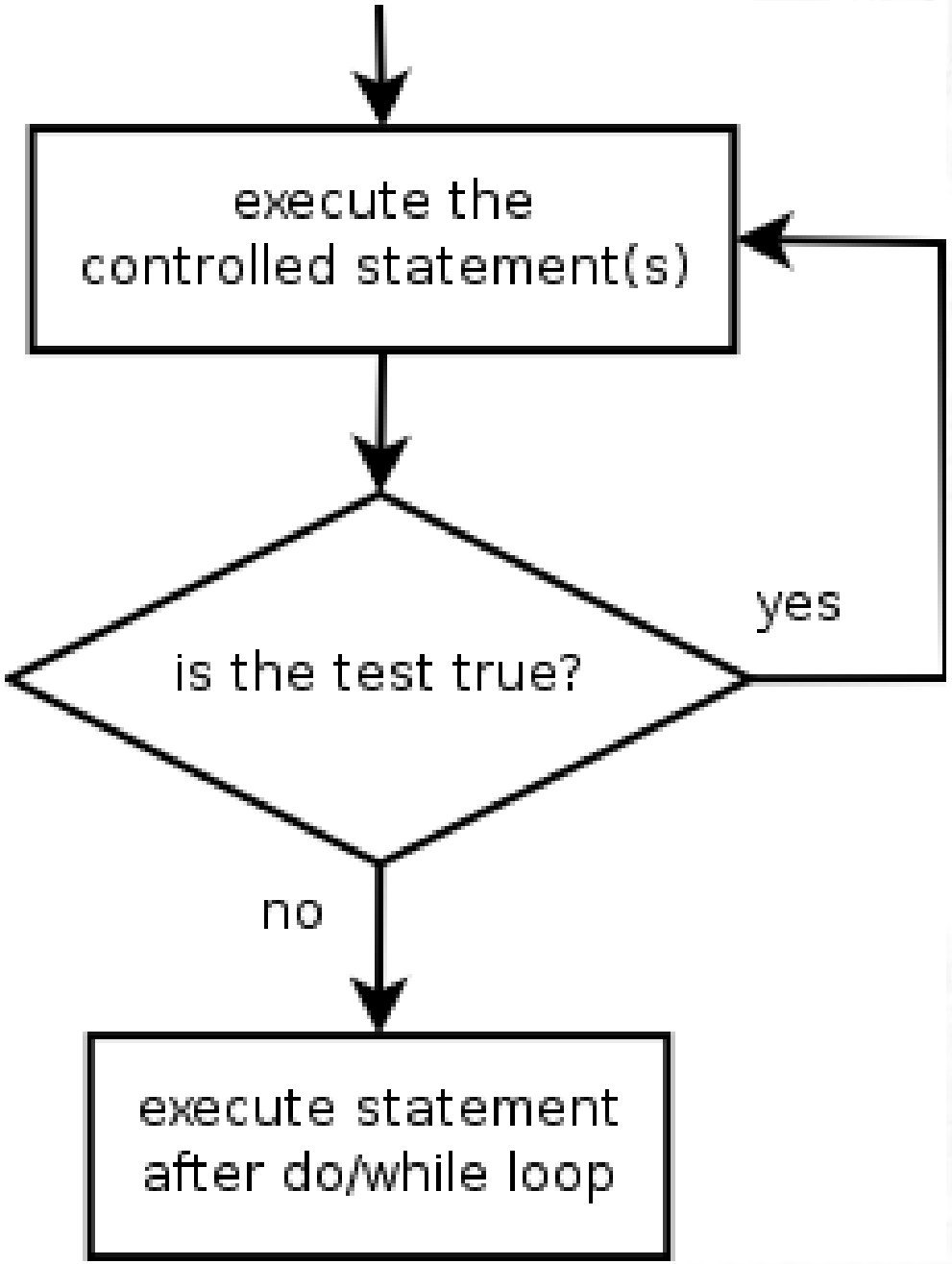
- The do/while loop, general syntax:

```
do {
    <statement(s)> ;
} while (<condition>);
```

  - Example:

```
// roll until we get a number other than 3
Random rand = new Random();
int dice;
do {
    dice = rand.nextInt();
} while (dice == 3);
```

do/while loop flow chart



"Forever" loop with break

- **`break` statement**: Immediately exits a loop.
  - Can be used to write a loop whose test is in the middle.
  - Such loops are often called *"forever" loops* because their header's boolean test is often changed to a trivial `true`.
- "forever" loop, general syntax:

```
while (true) {
    <statement(s)> ;

    if (<condition>) {
        break;
    }

    <statement(s)> ;
}
```

More correct code

- Another correct sentinel loop solution using `break`:

```
Scanner console = new Scanner(System.in);
int sum = 0;
while (true) {
    System.out.print("Enter a number (-1 to quit): ");
    int inputNumber = console.nextInt();
    if (inputNumber == -1) {  // don't add -1 to sum
        break;
    }
    sum += inputNumber;       // inputNumber != -1 here
}

System.out.println("The total was " + sum);
```

User errors

- suggested reading: 5.3

Testing for valid user input

- A `Scanner` object has methods that can be used to "look ahead" to test whether the upcoming input token is of a given type:

Method	Description
`hasNext()`	Whether the next token can be read as a `String` *(always true for console input)*
`hasNextInt()`	Whether the next token can be read as an `int`
`hasNextDouble()`	Whether the next token can be read as a `double`
`hasNextLine()`	Whether the next line of input can be read as a `String` *(always true for console input)*

- Each method waits for the user to type input and press Enter, then reports a `true` or `false` answer based on what was typed.
  - The `hasNext` and `hasNextLine` methods are not useful until we learn how to read input from files in Chapter 6.

Scanner condition example

- The `hasNext` methods are useful for testing whether the user typed the kind of token we wanted.
  - This way we can avoid potential exceptions from input mismatches.
  - Example:

```
Scanner console = new Scanner(System.in);
System.out.print("How old are you? ");

if (console.hasNextInt()) {
    int age = console.nextInt();   // will not throw an exception
    System.out.println("Retire in " + (65 - age) + " years.");
} else if (console.hasNextDouble()) {
    System.out.println("Please use a whole number for your age!");
} else {
    System.out.println("You did not type a number.");
}
```

Assertions

- suggested reading: 5.5

Logical assertions

- **assertion**: A statement that is either true or false.

Examples:

- Java was created in 1995.
- The sky is purple.
- 23 is a prime number.
- 10 is greater than 20.
- x divided by 2 equals 7. *(depends on the value of x)*

Assertions in code

- We can make assertions about our code and ask whether they are true at various points in the code.
  - Valid answers are ALWAYS, NEVER, or SOMETIMES.

```
System.out.print("Type a nonnegative number: ");
double number = console.nextDouble();
// Point A: is number < 0.0 here?        (SOMETIMES)

while (number < 0.0) {
    // Point B: is number < 0.0 here?    (ALWAYS)
    System.out.print("Negative; try again: ");

    number = console.nextDouble();
    // Point C: is number < 0.0 here?    (SOMETIMES)
}

// Point D: is number < 0.0 here?        (NEVER)
```

Assertion example 1

```
public static int mystery(Scanner console) {
    int prev = 0;
    int count = 0;
    int next = console.nextInt();
    // Point A
    while (next != 0) {
        // Point B
        if (next == prev) {
            // Point C
            count++;
        }
        prev = next;
        next = console.nextInt();
        // Point D
    }
    // Point E
    return count;
}
```

Which of the following assertions are true at which point(s) in the code?
Choose ALWAYS, NEVER, or SOMETIMES.

	next == 0	prev == 0	next == prev
Point A	SOMETIMES	ALWAYS	SOMETIMES
Point B	NEVER	SOMETIMES	SOMETIMES
Point C	NEVER	NEVER	ALWAYS
Point D	SOMETIMES	NEVER	SOMETIMES
Point E	ALWAYS	SOMETIMES	SOMETIMES

Assertion example 2

```
public static void mystery(int x, int y) {
    int z = 0;

    // Point A
    while (x >= y) {
        // Point B
        x -= y;

        // Point C
        z++;

        // Point D
    }

    // Point E
    System.out.println(z +
            " " + x);
}
```

Which of the following assertions are true at which point(s) in the code?
Choose ALWAYS, NEVER, or SOMETIMES.

	x < y	x == y	z == 0
Point A	SOMETIMES	SOMETIMES	ALWAYS
Point B	NEVER	SOMETIMES	SOMETIMES
Point C	SOMETIMES	SOMETIMES	SOMETIMES
Point D	SOMETIMES	SOMETIMES	NEVER
Point E	ALWAYS	NEVER	SOMETIMES

Assertion example 3

```
// pre : y >= 0,   post: returns x^y
public static int pow(int x, int y) {
    int prod = 1;

    // Point A
    while (y > 0) {
        // Point B
        if (y % 2 == 0) {
            // Point C
            x *= x;
            y /= 2;

            // Point D
        } else {
            // Point E
            prod *= x;
            y--;
            // Point F
         }
         // Point G
     }
     // Point H
     return prod;
}
```

Which of the following assertions are true at which point(s) in the code?
Choose ALWAYS, NEVER, or SOMETIMES.

	y == 0	y % 2 == 0
Point A	SOMETIMES	SOMETIMES
Point B	NEVER	SOMETIMES
Point C	NEVER	ALWAYS
Point D	NEVER	SOMETIMES
Point E	NEVER	NEVER
Point F	SOMETIMES	ALWAYS
Point G	SOMETIMES	SOMETIMES
Point H	ALWAYS	ALWAYS