7

Arrays

Now go, write it before them in a table, and note it in a book.

— Isaiah 30:8

To go beyond is as wrong as to fall short.

— Confucius

Begin at the beginning,… and go on till you come to the end: then stop.

— Lewis Carroll

OBJECTIVES

In this chapter you will learn:

- What arrays are.
- To use arrays to store data in and retrieve data from lists and tables of values.
- To declare an array, initialize an array and refer to individual elements of an array.
- To use the enhanced `for` statement to iterate through arrays.
- To pass arrays to methods.
- To declare and manipulate multidimensional arrays.
- To write methods that use variable-length argument lists.
- To read command-line arguments into a program.

Outline

7.1 Introduction

- **Arrays**
  - **Data structures**
  - **Related data items of same type**
  - **Remain same size once created**
    - **Fixed-length entries**

7.2 Arrays

- **Array**
  - **Group of variables**
    - **Have same type**
  - **Reference type**

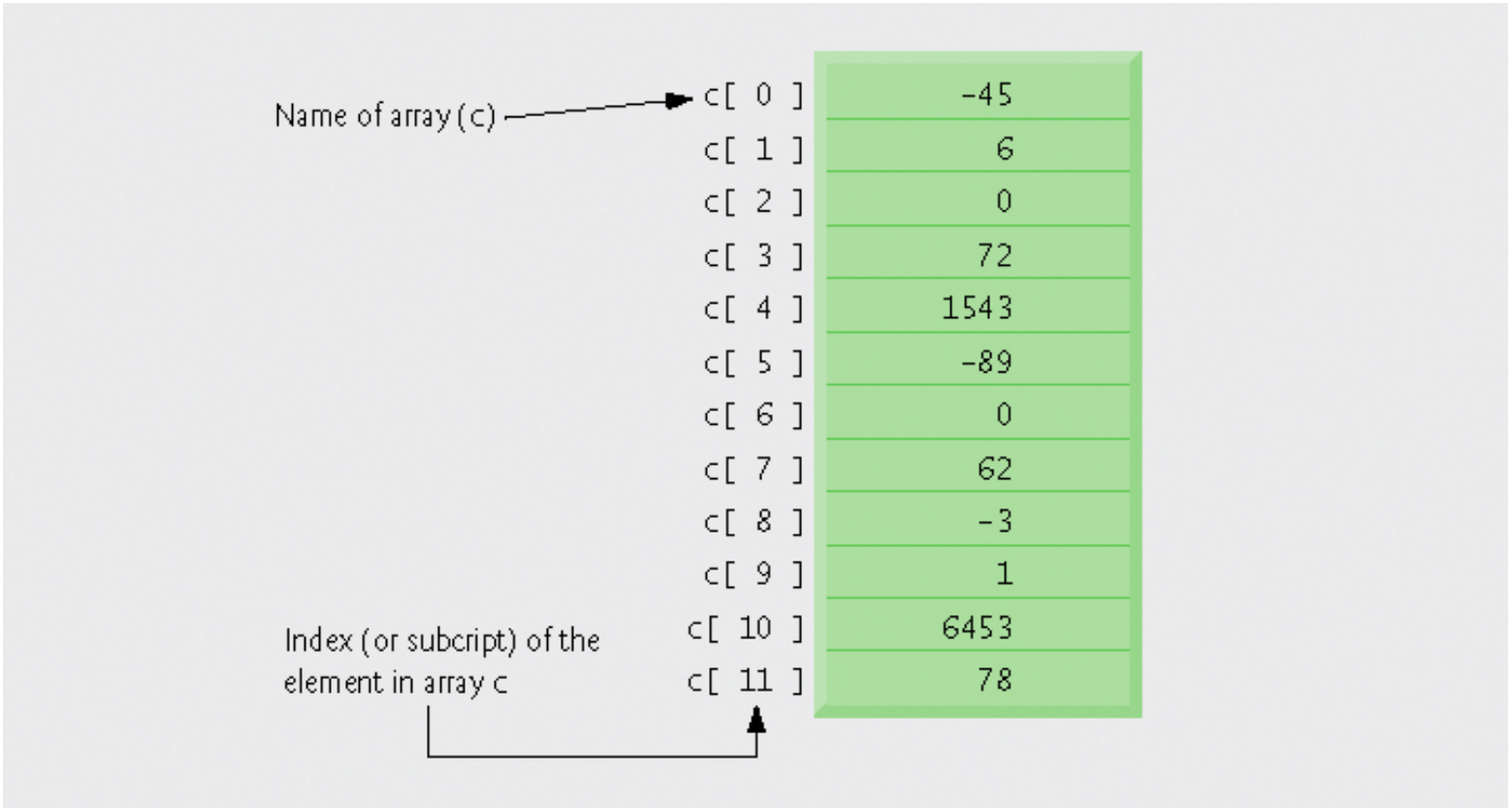


Fig. 7.1 | A 12-element array.

7.2 Arrays (Cont.)

- **Index**
  - **Also called subscript**
  - **Position number in square brackets**
  - **Must be positive integer or integer expression**
  - **First element has index zero**

```
a = 5;
b = 6;
c[ a + b ] += 2;
```

- **Adds 2 to c[11]**

Common Programming Error 7.1

Using a value of type `long` as an array index results in a compilation error. An index must be an `int` value or a value of a type that can be promoted to int—namely, `byte`, `short` or `char`, but not `long`.

7.2 Arrays (Cont.)

- **Examine array `c`**
  - **`c` is the array *name***
  - **`c.length` accesses array `c`'s *length***
  - **`c` has 12 *elements* (`c[0]`, `c[1]`, … `c[11]`)**
    - **The *value* of `c[0]` is `-45`**

7.3 Declaring and Creating Arrays

- **Declaring and Creating arrays**
  - **Arrays are objects that occupy memory**
  - **Created dynamically with keyword new**

```
int c[] = new int[ 12 ];
```

    - **Equivalent to**

```
int c[];  // declare array variable
c = new int[ 12 ]; // create array
```

  - **We can create arrays of objects too**

```
String b[] = new String[ 100 ];
```

Common Programming Error 7.2

In an array declaration, specifying the number of elements in the square brackets of the declaration (`e.g., int c[ 12 ];`) is a syntax error.

Good Programming Practice 7.1

For readability, declare only one variable per declaration. Keep each declaration on a separate line, and include a comment describing the variable being declared.

Common Programming Error 7.3

Declaring multiple array variables in a single declaration can lead to subtle errors. Consider the declaration `int[] a, b, c;`. If `a`, `b` and `c` should be declared as array variables, then this declaration is correct—placing square brackets directly following the type indicates that all the identifiers in the declaration are array variables. However, if only `a` is intended to be an array variable, and `b` and `c` are intended to be individual int variables, then this declaration is incorrect—the declaration `int a[], b, c;` would achieve the desired result.

7.4 Examples Using Arrays

- Declaring arrays
- Creating arrays
- Initializing arrays
- Manipulating array elements

7.4 Examples Using Arrays

- **Creating and initializing an array**
  - **Declare array**
  - **Create array**
  - **Initialize array elements**

Outline

```
1  // Fig. 7.2: InitArray.java
2  // Creating an array.
3
4  public class InitArray
5  {
6     public static void main( Stri
7     {
8        int array[]; // declare array named array
9
10       array = new int[ 10 ]; // create the sp
11
12       System.out.printf( "%s%8s\n", "Index", "Value" ); // column headings
13
14       // output each array element's value
15       for ( int counter = 0; counter < array.length; counter++ )
16          System.out.printf( "%5d%8d\n", counter, array[ counter ] );
17    } // end main
18 } // end class InitArray
```

```
Index   Value
    0       0
    1       0
    2       0
    3       0
    4       0
    5       0
    6       0
    7       0
    8       0
    9       0
```

Declare `array` as an array of `int`s

Create 10 `int`s for `array`; each `int` is initialized to 0 by default

`array.length` returns length of `array`

Each `int` is initialized to 0 by default

`array[counter]` returns `int` associated with index in `array`

InitArray.java

Line 8
Declare array as an array of **int**s

Line 10
Create 10 **int**s for array; each **int** is initialized to **0** by default

Line 15
array.length returns length of array

Line 16
array[counter] returns **int** associated with index in array

Program output

7.4 Examples Using Arrays (Cont.)

- **Using an array initializer**
  - Use *initializer list*
    - Items enclosed in braces ({})
    - Items in list separated by commas

```
int n[] = { 10, 20, 30, 40, 50 };
```

      - Creates a five-element array
      - Index values of 0, 1, 2, 3, 4
  - Do not need keyword new

```
1  // Fig. 7.3: InitArray.java
2  // Initializing the elements of an array with an array initializer.
3
4  public class InitArray
5  {
6     public static void main( String args[] )
7     {
8        // initializer list specifies the value for each element
9        int array[] = { 32, 27, 64, 18, 95, 14, 90, 70, 60, 37 };
10
11       System.out.printf( "%s%8s\n", "Index", "Value" ); // column headings
12
13       // output each array element's value
14       for ( int counter = 0; counter < array.length; counter++ )
15          System.out.printf( "%5d%8d\n", counter, array[ counter ] );
16    } // end main
17 } // end class InitArray
```

Declare `array` as an array of `int`s

Compiler uses initializer list to allocate array

```
Index   Value
    0      32
    1      27
    2      64
    3      18
    4      95
    5      14
    6      90
    7      70
    8      60
    9      37
```

Outline

itArray.java

Line 9
Declare array as an array of ints

Line 9
Compiler uses initializer list to allocate array

Program output

7.4 Examples Using Arrays (Cont.)

- **Calculating a value to store in each array element**
  - **Initialize elements of 10-element array to even integers**

Outline

```
1  // Fig. 7.4: InitArray.java
2  // Calculating values to be placed into elements of an array.
3
4  public class InitArray
5  {
6     public static void main( String args[] )
7     {
8        final int ARRAY_LENGTH = 10; // declare constant
9        int array[] = new int[ ARRAY_LENGTH ]; // create ar
10
11       // calculate value for each array element
12       for ( int counter = 0; counter < array.length; counter++ )
13          array[ counter ] = 2 + 2 * counter;
14
15       System.out.printf( "%s%8s\n", "Index", "Value" ); // column headings
16
17       // output each array element's value
18       for ( int counter = 0; counter < array.length; counter++ )
19          System.out.printf( "%5d%8d\n", counter
20    } // end main
21 } // end class InitArray
```

Declare constant variable ARRAY_LENGTH using the `final` modifier

Declare and create `array` that contains 10 `int`s

Use `array` index to assign array value

```
Index   Value
    0       2
    1       4
    2       6
    3       8
    4      10
    5      12
    6      14
    7      16
    8      18
    9      20
```

InitArray.java

8
are constant
variable

Line 9
Declare and
create array that
contains 10 ints

Line 13
Use array index
to assign array

Program output

Good Programming Practice 7.2

Constant variables also are called named constants or read-only variables. Such variables often make programs more readable than programs that use literal values (e.g., 10)—a named constant such as ARRAY_LENGTH clearly indicates its purpose, whereas a literal value could have different meanings based on the context in which it is used.

Common Programming Error 7.4

Assigning a value to a constant after the variable has been initialized is a compilation error.

Common Programming Error 7.5

Attempting to use a constant before it is initialized is a compilation error.

7.4 Examples Using Arrays (Cont.)

- **Summing the elements of an array**
  - **Array elements can represent a series of values**
    - **We can sum these values**

```
1  // Fig. 7.5: SumArray.java
2  // Computing the sum of the elements of
3
4  public class SumArray
5  {
6     public static void main( String args[] )
7     {
8        int array[] = { 87, 68, 94, 100, 83, 78, 85, 91, 76, 87 };
9        int total = 0;
10
11       // add each element's value to total
12       for ( int counter = 0; counter < array.length; counter++ )
13          total += array[ counter ];
14
15       System.out.printf( "Total of array elements: %d\n",   total );
16    } // end main
17 } // end class SumArray
```

Declare `array` with initializer list

Sum all `array` values

```
Total of array elements: 849
```

Program output

Outline

SumArray.java

Line 8
Declare array with initializer list

Lines 12-13
Sum all array values

7.4 Examples Using Arrays (Cont.)

- **Using bar charts to display array data graphically**
  - **Present data in graphical manner**
    - **E.g., bar chart**
  - **Examine the distribution of grades**

```
1  // Fig. 7.6: BarChart.java
2  // Bar chart printing program.
3
4  public class BarChart
5  {
6     public static void main( String args[] )
7     {
8        int array[] = { 0, 0, 0, 0, 0, 0, 1, 2, 4, 2, 1 };
9
10       System.out.println( "Grade distribution:" );
11
12       // for each array element, output a bar of the chart
13       for ( int counter = 0; counter < array.length; counter++ )
14       {
15          // output bar label ( "00-09: ", ..., "90-99: ", "100: " )
16          if ( counter == 10 )
17             System.out.printf( "%5d: ", 100 );
18          else
19             System.out.printf( "%02d-%02d: ",
20                counter * 10, counter * 10 + 9 );
21
22          // print bar of asterisks
23          for ( int stars = 0; stars < array[ counter ]; stars++ )
24             System.out.print( "*" );
25
26          System.out.println(); // start a new line of output
27       } // end outer for
28    } // end main
29 } // end class BarChart
```

Declare `array` with initializer list

Use the `0` flag to display one-digit grade with a leading 0

For each `array` element, print associated number of asterisks

Outline

BarChart.java

(1 of 2)

Line 8
Declare array with initializer list

Line 19
Use the `0` flag to display one-digit grade with a leading 0

```
Grade distribution:
00-09:
10-19:
20-29:
30-39:
40-49:
50-59:
60-69: *
70-79: **
80-89: ****
90-99: **
  100: *
```

Outline

BarChart.java

(2 of 2)

Program output

7.4 Examples Using Arrays (Cont.)

- **Using the elements of an array as counters**
  - **Use a series of counter variables to summarize data**

Outline

```
1  // Fig. 7.7: RollDie.java
2  // Roll a six-sided die 6000 times.
3  import java.util.Random;
4
5  public class RollDie
6  {
7     public static void main( String args[] )
8     {
9        Random randomNumbers = new Random(); // random number generator
10       int frequency[] = new int[ 7 ]; // array of frequency counters
11
12       // roll die 6000 times; use die value as frequency ind
13       for ( int roll = 1; roll <= 6000; roll++ )
14          ++frequency[ 1 + randomNumbers.nextInt( 6 ) ];
15
16       System.out.printf( "%s%10s\n"
17
18       // output each array element's value
19       for ( int face = 1; face < frequency.length; face++ )
20          System.out.printf( "%4d%10d\n", face, frequency[ face ] );
21    } // end main
22 } // end class RollDie
```

```
Face Frequency
   1       988
   2       963
   3      1018
   4      1041
   5       978
   6      1012
```

Declare `frequency` as array of 7 `int`s

Generate 6000 random integers in range 1-6

Increment `frequency` values at index associated with random number

...Die.java

Line 10
Declare
frequency as
...of 7 ints

...13-14
Generate 6000
random integers
in range 1-6

Line 14
Increment
frequency values
at index
associated with
random number

Program output

7.4 Examples Using Arrays (Cont.)

- **Using arrays to analyze survey results**
  - **40 students rate the quality of food**
    - **1-10 Rating scale: 1 means awful, 10 means excellent**
  - **Place 40 responses in array of integers**
  - **Summarize results**

```
1  // Fig. 7.8: StudentPoll.java
2  // Poll analysis program.
3
4  public class StudentPoll
5  {
6     public static void main( String args[] )
7     {
8        // array of survey responses
9        int responses[] = { 1, 2, 6, 4, 8, 5, 9, 7, 8, 10,
10          10, 3, 8, 2, 7, 6, 5, 7, 6, 8, 6, 7, 5, 6, 6, 5
11          4, 8, 6, 8, 10 };
12       int frequency[] = new int[ 11 ]; // array of frequency counters
13
14       // for each answer, select responses element and use that value
15       // as frequency index to determine element to increment
16       for ( int answer = 0; answer < responses.length; answer++ )
17          ++frequency[ responses[ answer ] ];
18
19       System.out.printf( "%s%10s", "Rating", "Frequency" );
20
21       // output each array element's value
22       for ( int rating = 1; rating < frequency.length; rating++ )
23          System.out.printf( "%d%10d", rating, frequency[ rating ] );
24    } // end main
25 } // end class StudentPoll
```

Declare `responses` as array to store 40 responses

Declare `frequency` as array of 11 `int` and ignore the first element

For each response, increment `frequency` values at index associated with that response

Outline

StudentPoll.java

(1 of 2)

onses as array to store 40 responses

Line 12 Declare frequency as array of 11 int e the ement

-17 response, increment frequency values at index associated with that response

```
Rating Frequency
     1         2
     2         2
     3         2
     4         2
     5         5
     6        11
     7         5
     8         7
     9         1
    10         3
```

Outline

StudentPoll.java

(2 of 2)

Program output

Error-Prevention Tip 7.1

An exception indicates that an error has occurred in a program. A programmer often can write code to recover from an exception and continue program execution, rather than abnormally terminating the program. When a program attempts to access an element outside the array bounds, an `ArrayIndexOutOfBoundsException` occurs. Exception handling is discussed in Chapter 13.

Error-Prevention Tip 7.2

When writing code to loop through an array, ensure that the array index is always greater than or equal to 0 and less than the length of the array. The loop-continuation condition should prevent the accessing of elements outside this range.

7.5 Case Study: Card Shuffling and Dealing Simulation

- **Program simulates card shuffling and dealing**
  - **Use random number generation**
  - **Use an array of reference type elements to represent cards**
  - **Three classes**
    - **Card**
      - **Represents a playing card**
    - **DeckOfCards**
      - **Represents a deck of 52 playing cards**
    - **DeckOfCardsTest**
      - **Demonstrates card shuffling and dealing**

Outline

Card.java

Lines 17-20

```
1  // Fig. 7.9: Card.java
2  // Card class represents a playing card.
3
4  public class Card
5  {
6     private String face; // face of card ("Ace", "Deuce", ...)
7     private String suit; // suit of card ("Hearts", "Diamonds", ...)
8
9     // two-argument constructor initializes card's face and suit
10    public Card( String cardFace, String cardSuit )
11    {
12       face = cardFace; // initialize face of card
13       suit = cardSuit; // initialize suit of card
14    } // end two-argument Card constructor
15
16    // return String representation of Card
17    public String toString()
18    {
19       return face + " of " + suit;
20    } // end method toString
21 } // end class Card
```

Return the string representation of a card

Outline

```
1  // Fig. 7.10: DeckOfCards.java
2  // DeckOfCards class represents a deck of playing cards.
3  import java.util.Random;
4
5  public class DeckOfCards
6  {
7     private Card deck[]; // array of Card objects
8     private int currentCard; // index of next Card to be dea
9     private final int NUMBER_OF_CARDS = 52; // constant number of Cards
10    private Random randomNumbers; // random number generator
11
12    // constructor fills deck of Cards
13    public DeckOfCards()
14    {
15       String faces[] = { "Ace", "Deuce
16          "Seven", "Eight", "Nine", "Te
17       String suits[] = { "Hearts", "Di
18
19       deck = new Card[ NUMBER_OF_CARDS ]; // create array of Card objects
20       currentCard = 0; // set currentCard so first Card dealt is deck[ 0 ]
21       randomNumbers = new Random(); // create random nu
22
23       // populate deck with Card objects
24       for ( int count = 0; count < deck.length; count++ )
25          deck[ count ] =
26             new Card( faces[ count % 13 ], suits[ count / 13 ] );
27    } // end DeckOfCards constructor
```

Declare `deck` as array to store `Card` objects

Constant `NUMBER_OF_CARDS` indicates the number of Cards in the deck

Declare and initialize `faces` with `String`s that represent the face of card

Declare and initialize `suits` with `String`s that represent the suit of card

Fill the `deck` array with `Card`s

(1 of 2)

Line 7

Line 9

Lines 15-16

Line 17

Lines 24-26

Outline

DeckOfCards.java

(2 of 2)

```
28
29    // shuffle deck of Cards with one-pass algorithm
30    public void shuffle()
31    {
32       // after shuffling, dealing should start at deck[ 0 ] again
33       currentCard = 0; // reinitialize currentCard
34
35       // for each Card, pick another random Card and swap them
36       for ( int first = 0; first < deck.length; first++ )
37       {
38          // select a random number between 0 and 51
39          int second =  randomNumbers.nextInt( NUMBER_OF_CARDS );
40
41          // swap current Card with randomly selected Card
42          Card temp = deck[ first ];
43          deck[ first ] = deck[ second ];
44          deck[ second ] = temp;
45       } // end for
46    } // end method shuffle
47
48    // deal one Card
49    public Card dealCard()
50    {
51       // determine whether Cards remain to be dealt
52       if ( currentCard < deck.length )
53          return deck[ currentCard++ ]; // return current Card in array
54       else
55          return null; // return null to indicate that all Cards were dealt
56    } // end method dealCard
57 } // end class DeckOfCards
```

Swap current `Card` with randomly selected `Card`

-44

Line 52

Determine whether `deck` is empty

Outline

DeckOfCardsTest.java

(1 of 2)

```
1  // Fig. 7.11: DeckOfCardsTest.java
2  // Card shuffling and dealing application.
3
4  public class DeckOfCardsTest
5  {
6     // execute application
7     public static void main( String args[] )
8     {
9        DeckOfCards myDeckOfCards = new DeckOfCards();
10       myDeckOfCards.shuffle(); // place Cards in random order
11
12       // print all 52 Cards in the order in which they are dealt
13       for ( int i = 0; i < 13; i++ )
14       {
15          // deal and print 4 Cards
16          System.out.printf( "%-20s%-20s%-20s%-20s\n",
17             myDeckOfCards.dealCard(), myDeckOfCards.dealCard(),
18             myDeckOfCards.dealCard(), myDeckOfCards.dealCard() );
19       } // end for
20    } // end main
21 } // end class DeckOfCardsTest
```

```
Six of Spades       Eight of Spades     Six of Clubs        Nine of Hearts
Queen of Hearts     Seven of Clubs      Nine of Spades      King of Hearts
Three of Diamonds   Deuce of Clubs      Ace of Hearts       Ten of Spades
Four of Spades      Ace of Clubs        Seven of Diamonds   Four of Hearts
Three of Clubs      Deuce of Hearts     Five of Spades      Jack of Diamonds
King of Clubs       Ten of Hearts       Three of Hearts     Six of Diamonds
Queen of Clubs      Eight of Diamonds   Deuce of Diamonds   Ten of Diamonds
Three of Spades     King of Diamonds    Nine of Clubs       Six of Hearts
Ace of Spades       Four of Diamonds    Seven of Hearts     Eight of Clubs
Deuce of Spades     Eight of Hearts     Five of Hearts      Queen of Spades
Jack of Hearts      Seven of Spades     Four of Clubs       Nine of Diamonds
Ace of Diamonds     Queen of Diamonds   Five of Clubs       King of Spades
Five of Diamonds    Ten of Clubs        Jack of Spades      Jack of Clubs
```

Outline

DeckOfCardsTest

.java

(2 of 2)

7.6 Enhanced `for` Statement

- **Enhanced `for` statement**
  - **Iterates through elements of an array or a collection without using a counter**
  - **Syntax**

```
for ( parameter : arrayName )
   statement
```

Outline

EnhancedForTest.java

```
1  // Fig. 7.12: EnhancedForTest.java
2  // Using enhanced for statement to total integers in an array.
3
4  public class EnhancedForTest
5  {
6     public static void main( String args[] )
7     {
8        int array[] = { 87, 68, 94, 100, 83, 78, 85, 91, 76, 87 };
9        int total = 0;
10
11       // add each element's value to total
12       for ( int number : array )
13          total += number;
14
15       System.out.printf( "Total of array elements: %d\n", total );
16    } // end main
17 } // end class EnhancedForTest
```

```
Total of array elements: 849
```

For each iteration, assign the next element of `array` to `int` variable `number`, then add it to `total`

7.6 Enhanced for Statement (Cont.)

- **Lines 12-13 are equivalent to**

```
for ( int counter = 0; counter < array.length; counter++ )
    total += array[ counter ];
```

- **Usage**
  - **Can access array elements**
  - **Cannot modify array elements**
  - **Cannot access the counter indicating the index**

7.7 Passing Arrays to Methods

- To pass array argument to a method
  - Specify array name without brackets
    - Array `hourlyTemperatures` is declared as

```
int hourlyTemperatures = new int[ 24 ];
```

    - The method call

```
modifyArray( hourlyTemperatures );
```

    - Passes array `hourlyTemperatures` to method `modifyArray`

Outline

PassArray.java

(1 of 2)

Line 9

Line 19

```
1  // Fig. 7.13: PassArray.java
2  // Passing arrays and individual array elements to methods.
3
4  public class PassArray
5  {
6     // main creates array and calls modifyArray and modifyElement
7     public static void main( String args[] )
8     {
9        int array[] = { 1, 2, 3, 4, 5 };
10
11       System.out.println(
12          "Effects of passing reference to entire array:\n" +
13          "The values of the original array are:" );
14
15       // output original array elements
16       for ( int value : array )
17          System.out.printf( "   %d", value );
18
19       modifyArray( array ); // pass array reference
20       System.out.println( "\n\nThe values of the modified array are:" );
21
22       // output modified array elements
23       for ( int value : array )
24          System.out.printf( "   %d", value );
25
26       System.out.printf(
27          "\n\nEffects of passing array element value:\n" +
28          "array[3] before modifyElement: %d\n", array[ 3 ] );
```

Declare 5-int array with initializer list

Pass entire array to method modifyArray

```
29
30       modifyElement( array[ 3 ] ); // attempt to modify array[ 3 ]
31       System.out.printf(
32          "array[3] after modifyElement
33    } // end main
34
35    // multiply each element of an array by 2
36    public static void modifyArray( int array2[] )
37    {
38       for ( int counter = 0; counter < array2.length; counter++ )
39          array2[ counter ] *= 2;
40    } // end method modifyArray
41
42    // multiply argument by 2
43    public static void modifyElement( int element )
44    {
45       element *= 2;
46       System.out.printf(
47          "Value of element in modifyElement: %d\n", element );
48    } // end method modifyElement
49 } // end class PassArray
```

Pass array element `array[3]` to method `modifyElement`

Method `modifyArray` manipulates the array directly

Method `modifyElement` manipulates a primitive's copy

```
Effects of passing reference to entire array:
The values of the original array are:
   1   2   3   4   5

The values of the modified array are:
   2   4   6   8   10

Effects of passing array element value:
array[3] before modifyElement: 8
Value of element in modifyElement: 16
array[3] after modifyElement: 8
```

Outline

ava
(2 of 2)

Line 30

Lines 36-40

Lines 43-48

Program output

7.7 Passing Arrays to Methods (Cont.)

- Notes on passing arguments to methods
  - Two ways to pass arguments to methods
    - Pass-by-value
      - Copy of argument's value is passed to called method
      - Every primitive type is passed-by-value
    - Pass-by-reference
      - Caller gives called method direct access to caller's data
      - Called method can manipulate this data
      - Improved performance over pass-by-value
      - Every object is passed-by-reference
        - Arrays are objects
        - Therefore, arrays are passed by reference

Performance Tip 7.1

Passing arrays by reference makes sense for performance reasons. If arrays were passed by value, a copy of each element would be passed. For large, frequently passed arrays, this would waste time and consume considerable storage for the copies of the arrays.

7.8 Case Study: Class GradeBook Using an Array to Store Grades

- **Further evolve class GradeBook**
- **Class GradeBook**
  - **Represents a grade book that stores and analyzes grades**
  - **Does not maintain individual grade values**
  - **Repeat calculations require reentering the same grades**
    - **Can be solved by storing grades in an array**

Outline

GradeBook.java

(1 of 5)

Line 7

Line 13

```
1  // Fig. 7.14: GradeBook.java
2  // Grade book using an array to store test grades.
3
4  public class GradeBook
5  {
6     private String courseName; // name of course this GradeBook represents
7     private int grades[]; // array of student grades
8
9     // two-argument constructor initializes courseName
10    public GradeBook( String name, int gradesArray[] )
11    {
12       courseName = name; // initialize courseName
13       grades = gradesArray; // store grades
14    } // end two-argument GradeBook constructor
15
16    // method to set the course name
17    public void setCourseName( String name )
18    {
19       courseName = name; // store the course name
20    } // end method setCourseName
21
22    // method to retrieve the course name
23    public String getCourseName()
24    {
25       return courseName;
26    } // end method getCourseName
27
```

Declare array `grades` to store individual grades

Assign the array's reference to instance variable `grades`

Outline

GradeBook.java

(2 of 5)

```
28    // display a welcome message to the GradeBook user
29    public void displayMessage()
30    {
31       // getCourseName gets the name of the course
32       System.out.printf( "Welcome to the grade book for\n%s!\n\n",
33          getCourseName() );
34    } // end method displayMessage
35
36    // perform various operations on the data
37    public void processGrades()
38    {
39       // output grades array
40       outputGrades();
41
42       // call method getAverage to calculate the average grade
43       System.out.printf( "\nClass average is %.2f\n", getAverage() );
44
45       // call methods getMinimum and getMaximum
46       System.out.printf( "Lowest grade is %d\nHighest grade is %d\n\n",
47          getMinimum(), getMaximum() );
48
49       // call outputBarChart to print grade distribution chart
50       outputBarChart();
51    } // end method processGrades
52
53    // find minimum grade
54    public int getMinimum()
55    {
56       int lowGrade = grades[ 0 ]; // assume grades[ 0 ] is smallest
57
```

```
58       // loop through grades array
59       for ( int grade : grades )
60       {
61          // if grade lower than lowGrade, assign it to lowGrade
62          if ( grade < lowGrade )
63             lowGrade = grade; // new lowest grade
64       } // end for
65
66       return lowGrade; // return lowest grade
67    } // end method getMinimum
68
69    // find maximum grade
70    public int getMaximum()
71    {
72       int highGrade = grades[ 0 ]; // assume grades[ 0 ] is largest
73
74       // loop through grades array
75       for ( int grade : grades )
76       {
77          // if grade greater than highGrade, assign it to highGrade
78          if ( grade > highGrade )
79             highGrade = grade; // new highest grade
80       } // end for
81
82       return highGrade; // return highest grade
83    } // end method getMaximum
84
```

Loop through `grades` to find the lowest grade

Loop through `grades` to find the highest grade

Outline

`radeBook.java`

(3 of 5)

Lines 59-64

Lines 75-80

```
85   // determine average grade for test
86   public double getAverage()
87   {
88      int total = 0; // initialize total
89
90      // sum grades for one student
91      for ( int grade : grades )
92         total += grade;
93
94      // return average of grades
95      return (double) total / grades.length;
96   } // end method getAverage
97
98   // output bar chart displaying grade distribution
99   public void outputBarChart()
100    {
101       System.out.println( "Grade distribution:" );
102
103       // stores frequency of grades in each range of 10 grades
104       int frequency[] = new int[ 11 ];
105
106       // for each grade, increment the appropriate frequency
107       for ( int grade : grades )
108          ++frequency[ grade / 10 ];
109
```

Loop through `grades` to sum grades for one student

Loop through `grades` to calculate frequency

Outline

`GradeBook.java`

(4 of 5)

Lines 91-92

Lines 107-108

Outline

GradeBook.java

(5 of 5)

Lines 134-136

```
110      // for each grade frequency, print bar in chart
111      for ( int count = 0; count < frequency.length; count++ )
112      {
113         // output bar label ( "00-09: ", ..., "90-99: ", "100: " )
114         if ( count == 10 )
115            System.out.printf( "%5d: ", 100 );
116         else
117            System.out.printf( "%02d-%02d: ",
118               count * 10, count * 10 + 9  );
119
120         // print bar of asterisks
121         for ( int stars = 0; stars < frequency[ count ]; stars++ )
122            System.out.print( "*" );
123
124         System.out.println(); // start a new line of output
125      } // end outer for
126   } // end method outputBarChart
127
128   // output the contents of the grades array
129   public void outputGrades()
130   {
131      System.out.println( "The grades are:\n" );
132
133      // output each student's grade
134      for ( int student = 0; student < grades.length; student++ )
135         System.out.printf( "Student %2d: %3d\n",
136            student + 1, grades[ student ] );
137   } // end method outputGrades
138 } // end class GradeBook
```

Loop through `grades` to display each grade

Software Engineering Observation 7.1

A test harness (or test application) is responsible for creating an object of the class being tested and providing it with data. This data could come from any of several sources. Test data can be placed directly into an array with an array initializer, it can come from the user at the keyboard, it can come from a file (as you will see in Chapter 14), or it can come from a network (as you will see in Chapter 24). After passing this data to the class's constructor to instantiate the object, the test harness should call upon the object to test its methods and manipulate its data. Gathering data in the test harness like this allows the class to manipulate data from several sources.

Outline

eBookTest

.java

(1 of 2)

Line 10

Line 13

```
1  // Fig. 7.15: GradeBookTest.java
2  // Creates GradeBook object using an array of grades.
3
4  public class GradeBookTest
5  {
6     // main method begins program execution
7     public static void main( String args[] )
8     {
9        // array of student grades
10       int gradesArray[] = { 87, 68, 94, 100, 83, 78, 85, 91, 76, 87 };
11
12       GradeBook myGradeBook = new GradeBook(
13          "CS101 Introduction to Java Programming", gradesArray );
14       myGradeBook.displayMessage();
15       myGradeBook.processGrades();
16    } // end main
17 } // end class GradeBookTest
```

Declare and initialize gradesArray with 10 elements

Pass gradesArray to GradeBook constructor

```
Welcome to the grade book for
CS101 Introduction to Java Programming!

The grades are:

Student  1:  87
Student  2:  68
Student  3:  94
Student  4: 100
Student  5:  83
Student  6:  78
Student  7:  85
Student  8:  91
Student  9:  76
Student 10:  87

Class average is 84.90
Lowest grade is 68
Highest grade is 100

Grade distribution:
00-09:
10-19:
20-29:
30-39:
40-49:
50-59:
60-69: *
70-79: **
80-89: ****
90-99: **
  100: *
```

Outline

GradeBookTest

.java

(2 of 2)

Program output

7.9 Multidimensional Arrays

- **Multidimensional arrays**
  - **Tables with rows and columns**
    - **Two-dimensional array**
    - **m-by-n array**

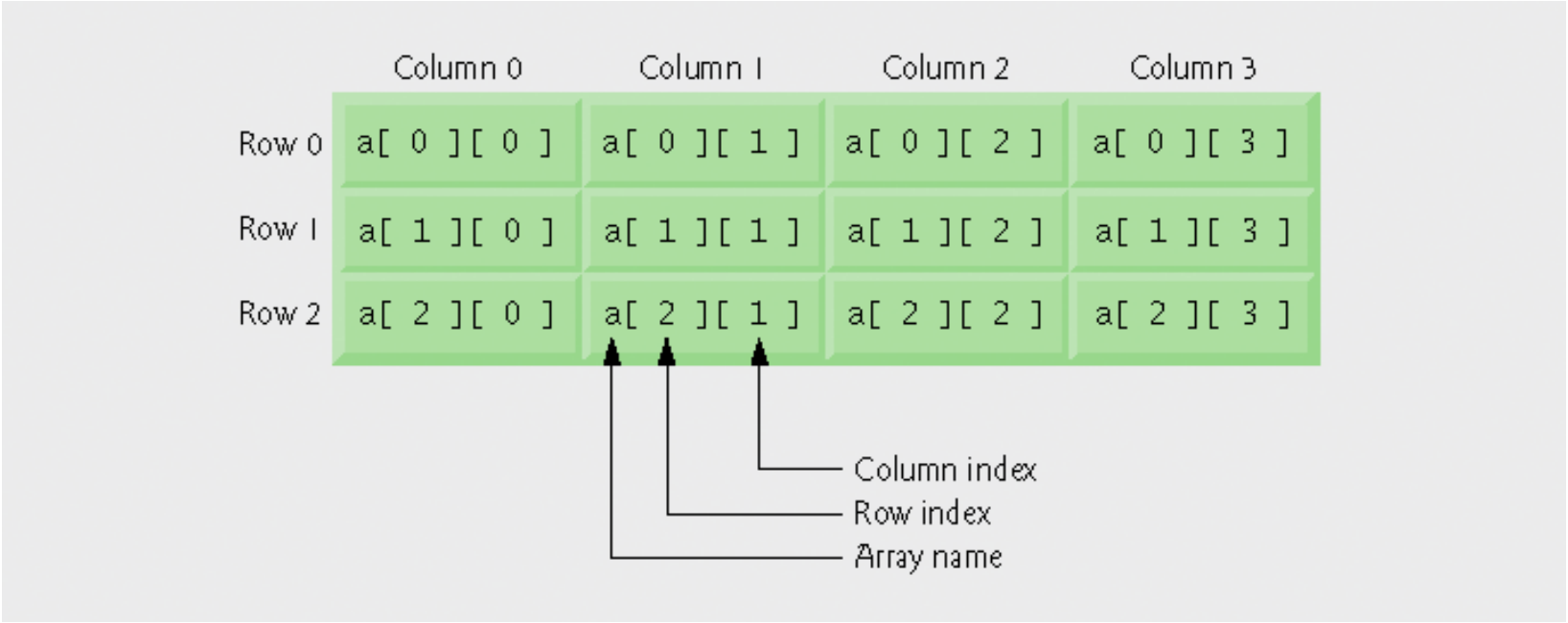


Fig. 7.16 | Two-dimensional array with three rows and four columns.

7.9 Multidimensional Arrays (Cont.)

- **Arrays of one-dimensional array**
  - **Declaring two-dimensional array `b[2][2]`**

```
int b[][] = { { 1, 2 }, { 3, 4 } };
```

    - **`1` and `2` initialize `b[0][0]` and `b[0][1]`**
    - **`3` and `4` initialize `b[1][0]` and `b[1][1]`**

```
int b[][] = { { 1, 2 }, { 3, 4, 5 } };
```

    - **row `0` contains elements `1` and `2`**
    - **row `1` contains elements `3`, `4` and `5`**

7.9 Multidimensional Arrays (Cont.)

- **Two-dimensional arrays with rows of different lengths**
  - **Lengths of rows in array are not required to be the same**
    - **E.g.,** `int b[][] = { { 1, 2 }, { 3, 4, 5 } };`

7.9 Multidimensional Arrays (Cont.)

- **Creating two-dimensional arrays with array-creation expressions**
  - 3-by-4 array

```
int b[][];
b = new int[ 3 ][ 4 ];
```

  - Rows can have different number of columns

```
int b[][];

b = new int[ 2 ][ ];   // create 2 rows
b[ 0 ] = new int[ 5 ]; // create 5 columns for row 0
b[ 1 ] = new int[ 3 ]; // create 3 columns for row 1
```

Outline

```
1  // Fig. 7.17: InitArray.java
2  // Initializing two-dimensional arrays.
3
4  public class InitArray
5  {
6     // create and output two-dimensional arrays
7     public static void main( String args[] )
8     {
9        int array1[][] = { { 1, 2, 3 }, { 4, 5, 6 } };
10       int array2[][] = { { 1, 2 }, { 3 }, { 4, 5, 6 } };
11
12       System.out.println( "Values in array1 by row are" );
13       outputArray( array1 ); // displays array1 by row
14
15       System.out.println( "\nValues in array2 by row are" );
16       outputArray( array2 ); // displays array2 by row
17    } // end main
18
```

Use nested array initializers to initialize `array1`

Use nested array initializers of different lengths to initialize `array2`

`InitArray.java`

(1 of 2)

Line 9

Line 10

```
19    // output rows and columns of a two-dimensional array
20    public static void outputArray( int array[][] )
21    {
22       // loop through array's rows
23       for ( int row = 0; row < array.length; row++ )
24       {
25          // loop through columns of current row
26          for ( int column = 0; column < array[ row ].length; column++ )
27             System.out.printf( "%d  ", array[ row ][ column ] );
28
29          System.out.println(); // start new line of output
30       } // end outer for
31    } // end method outputArray
32 } // end class InitArray
```

`array[row].length` returns number of columns associated with `row` subscript

Use double-bracket notation to access two-dimensional array values

```
Values in array1 by row are
1  2  3
4  5  6

Values in array2 by row are
1  2
3
4  5  6
```

Outline

`InitArray.java`

(2 of 2)

Line 26

Line 27

Program output

7.9 Multidimensional Arrays (Cont.)

- **Common multidimensional-array manipulations performed with `for` statements**
  - **Many common array manipulations use `for` statements**

E.g.,

```
for ( int column = 0; column < a[ 2 ].length; column++ )
      a[ 2 ][ column ] = 0;
```

7.10 Case Study: Class GradeBook Using a Two-Dimensional Array

- Class GradeBook
  - One-dimensional array
    - Store student grades on a single exam
  - Two-dimensional array
    - Store grades for a single student and for the class as a whole

Outline

GradeBook.java

(1 of 7)

Line 7

Line 10

```
1  // Fig. 7.18: GradeBook.java
2  // Grade book using a two-dimensional array to store grades.
3
4  public class GradeBook
5  {
6     private String courseName; // name of course this grade book represents
7     private int grades[][]; // two-dimensional array of student grades
8
9     // two-argument constructor initializes courseName and grades array
10    public GradeBook( String name, int gradesArray[][] )
11    {
12       courseName = name; // initialize courseName
13       grades = gradesArray; // store grades
14    } // end two-argument GradeBook constructor
15
16    // method to set the course name
17    public void setCourseName( String name )
18    {
19       courseName = name; // store the course name
20    } // end method setCourseName
21
22    // method to retrieve the course name
23    public String getCourseName()
24    {
25       return courseName;
26    } // end method getCourseName
27
```

Declare two-dimensional array grades

`GradeBook` constructor accepts a `String` and a two-dimensional array

Outline

GradeBook.java

(2 of 7)

```
28    // display a welcome message to the GradeBook user
29    public void displayMessage()
30    {
31       // getCourseName gets the name of the course
32       System.out.printf( "Welcome to the grade book for\n%s!\n\n",
33          getCourseName() );
34    } // end method displayMessage
35
36    // perform various operations on the data
37    public void processGrades()
38    {
39       // output grades array
40       outputGrades();
41
42       // call methods getMinimum and getMaximum
43       System.out.printf( "\n%s %d\n%s %d\n\n",
44          "Lowest grade in the grade book is", getMinimum(),
45          "Highest grade in the grade book is", getMaximum() );
46
47       // output grade distribution chart of all grades on all tests
48       outputBarChart();
49    } // end method processGrades
50
51    // find minimum grade
52    public int getMinimum()
53    {
54       // assume first element of grades array is smallest
55       int lowGrade = grades[ 0 ][ 0 ];
56
```

```
57       // loop through rows of grades array
58       for ( int studentGrades[] : grades )
59       {
60          // loop through columns of current row
61          for ( int grade : studentGrades
62          {
63             // if grade less than lowGra
64             if ( grade < lowGrade )
65                lowGrade = grade;
66          } // end inner for
67       } // end outer for
68
69       return lowGrade; // return lowest grade
70    } // end method getMinimum
71
72    // find maximum grade
73    public int getMaximum()
74    {
75       // assume first element of grades array is largest
76       int highGrade = grades[ 0 ][ 0 ];
77
```

Loop through rows of `grades` to find the lowest grade of any student

Outline

`GradeBook.java`

(3 of 7)

Lines 58-67

```
78      // loop through rows of grades array
79      for ( int studentGrades[] : grades )
80      {
81         // loop through columns of current row
82         for ( int grade : studentGrad
83         {
84            // if grade greater than h
85            if ( grade > highGrade )
86               highGrade = grade;
87         } // end inner for
88      } // end outer for
89
90      return highGrade; // return highest grade
91   } // end method getMaximum
92
93   // determine average grade for particular set of grades
94   public double getAverage( int setOfGrades[] )
95   {
96      int total = 0; // initialize total
97
98      // sum grades for one student
99      for ( int grade : setOfGrades )
100        total += grade;
101
102     // return average of grades
103     return (double) total / setOfGrades.length;
104  } // end method getAverage
105
```

Loop through rows of `grades` to find the highest grade of any student

Calculate a particular student's semester average

Outline

`GradeBook.java`

(4 of 7)

Lines 79-88

Lines 94-104

Outline

GradeBook.java

(5 of 7)

Lines 115-119

```
106    // output bar chart displaying overall grade distribution
107    public void outputBarChart()
108    {
109       System.out.println( "Overall grade distribution:" );
110
111       // stores frequency of grades in each range of 10 grades
112       int frequency[] = new int[ 11 ];
113
114       // for each grade in GradeBook, increment the appropriate frequency
115       for ( int studentGrades[] : grades )
116       {
117          for ( int grade : studentGrades )
118             ++frequency[ grade / 10 ];
119       } // end outer for
120
121       // for each grade frequency, print bar in chart
122       for ( int count = 0; count < frequency.length; count++ )
123       {
124          // output bar label ( "00-09: ", ..., "90-99: ", "100: " )
125          if ( count == 10 )
126             System.out.printf( "%5d: ", 100 );
127          else
128             System.out.printf( "%02d-%02d: ",
129                count * 10, count * 10 + 9  );
130
131          // print bar of asterisks
132          for ( int stars = 0; stars < frequency[ count ]; stars++ )
133             System.out.print( "*" );
```

Calculate the distribution of all student grades

Outline

GradeBook.java

(6 of 7)

```
134
135          System.out.println(); // start a new line of output
136       } // end outer for
137    } // end method outputBarChart
138
139    // output the contents of the grades array
140    public void outputGrades()
141    {
142       System.out.println( "The grades are:\n" );
143       System.out.print( "            " ); // align column heads
144
145       // create a column heading for each of the tests
146       for ( int test = 0; test < grades[ 0 ].length; test++ )
147          System.out.printf( "Test %d  ", test + 1 );
148
149       System.out.println( "Average" ); // student average column heading
150
151       // create rows/columns of text representing array grades
152       for ( int student = 0; student < grades.length; student++ )
153       {
154          System.out.printf( "Student %2d", student + 1 );
155
156          for ( int test : grades[ student ] ) // output student's grades
157             System.out.printf( "%8d", test );
158
```

```
159          // call method getAverage to calculate student's average grade;
160          // pass row of grades as the argument to getAverage
161          double average = getAverage( grades[ student ] );
162          System.out.printf( "%9.2f\n", average );
163       } // end outer for
164    } // end method outputGrades
165 } // end class GradeBook
```

Outline

GradeBook.java

(7 of 7)

Outline

```
1  // Fig. 7.19: GradeBookTest.java
2  // Creates GradeBook object using a two-dimensional array of grades.
3
4  public class GradeBookTest
5  {
6     // main method begins program execution
7     public static void main( String args[] )
8     {
9        // two-dimensional array of student grades
10       int gradesArray[][] = { { 87, 96, 70 },
11                               { 68, 87, 90 },
12                               { 94, 100, 90 },
13                               { 100, 81, 82 },
14                               { 83, 65, 85 },
15                               { 78, 87, 65 },
16                               { 85, 75, 83 },
17                               { 91, 94, 100 },
18                               { 76, 72, 84 },
19                               { 87, 93, 73 } };
20
21       GradeBook myGradeBook = new GradeB
22          "CS101 Introduction to Java Pro
23       myGradeBook.displayMessage();
24       myGradeBook.processGrades();
25    } // end main
26 } // end class GradeBookTest
```

Declare `gradesArray` as 10-by-3 array

Each row represents a student; each column represents an exam grade

.java

(1 of 2)

Lines 10-19

Outline

GradeBookTest

.java

(2 of 2)

Program output

```
Welcome to the grade book for
CS101 Introduction to Java Programming!

The grades are:

            Test 1  Test 2  Test 3  Average
Student  1      87      96      70    84.33
Student  2      68      87      90    81.67
Student  3      94     100      90    94.67
Student  4     100      81      82    87.67
Student  5      83      65      85    77.67
Student  6      78      87      65    76.67
Student  7      85      75      83    81.00
Student  8      91      94     100    95.00
Student  9      76      72      84    77.33
Student 10      87      93      73    84.33

Lowest grade in the grade book is 65
Highest grade in the grade book is 100

Overall grade distribution:
00-09:
10-19:
20-29:
30-39:
40-49:
50-59:
60-69: ***
70-79: ******
80-89: ***********
90-99: *******
  100: ***
```

7.11 Variable-Length Argument Lists

- **Variable-length argument lists**
  - **Unspecified number of arguments**
  - **Use ellipsis (...) in method's parameter list**
    - **Can occur only once in parameter list**
    - **Must be placed at the end of parameter list**
  - **Array whose elements are all of the same type**

```
1  // Fig. 7.20: VarargsTest.java
2  // Using variable-length argument lists.
3
4  public class VarargsTest
5  {
6     // calculate average
7     public static double average( double... numbers )
8     {
9        double total = 0.0; // initialize total
10
11       // calculate total using the enha
12       for ( double d : numbers )
13          total += d;
14
15       return total / numbe
16    } // end method average
17
18    public static void main( String args[] )
19    {
20       double d1 = 10.0;
21       double d2 = 20.0;
22       double d3 = 30.0;
23       double d4 = 40.0;
24
```

Method `average` receives a variable length sequence of `double`s

Calculate the total of the `double`s in the array

Access `numbers.length` to obtain the size of the `numbers` array

Outline

`VarargsTest.java`

(1 of 2)

Line 7

Lines 12-13

Line 15

Outline

```
25       System.out.printf( "d1 = %.1f\nd2 = %.1f\nd3 = %.1f\nd4 = %.1f\n\n",
26          d1, d2, d3, d4 );
27
28       System.out.printf( "Average of d1 and d2 is %.1f\n",
29          average( d1, d2 ) );
30       System.out.printf( "Average of d1, d2 and d
31          average( d1, d2, d3 ) );
32       System.out.printf( "Average of d1, d2, d3 and d4 is %.1f\n",
33          average( d1, d2, d3, d4 ) );
34    } // end main
35 } // end class VarargsTest
```

```
d1 = 10.0
d2 = 20.0
d3 = 30.0
d4 = 40.0

Average of d1 and d2 is 15.0
Average of d1, d2 and d3 is 20.0
Average of d1, d2, d3 and d4 is 25.0
```

Invoke method average with two arguments

Invoke method average with three arguments

Invoke method average with four arguments

VarargsTest.java

2)

Line 29

Line 31

Line 33

Program output

Common Programming Error 7.6

Placing an ellipsis in the middle of a method parameter list is a syntax error. An ellipsis may be placed only at the end of the parameter list.

7.12 Using Command-Line Arguments

- **Command-line arguments**
  - **Pass arguments from the command line**
    - `String args[]`
  - **Appear after the class name in the `java` command**
    - `java MyClass a b`
  - **Number of arguments passed in from command line**
    - `args.length`
  - **First command-line argument**
    - `args[ 0 ]`

Outline

InitArray.java

(1 of 2)

Line 6

Line 9

Line 16

Lines 20-21

Lines 24-25

```
1  // Fig. 7.21: InitArray.java
2  // Using command-line arguments to initialize an array.
3
4  public class InitArray
5  {
6     public static void main( String args[] )
7     {
8        // check number of command-line arguments
9        if ( args.length != 3 )
10          System.out.println(
11             "Error: Please re-enter                    " +
12             "an array                                  );
13       else
14       {
15          // get array size from first command-line argument
16          int arrayLength = Integer.parseInt( args[ 0 ] );
17          int array[] = new int[ arrayLength ]; // create array
18
19          // get initial value and increment from co
20          int initialValue = Integer.parseInt( args[
21          int increment = Integer.parseInt( args[ 2 ] );
22
23          // calculate value for each array element
24          for ( int counter = 0; counter < array.le
25             array[ counter ] = initialValue + incr
26
27          System.out.printf( "%s%8s\n", "Index", "Value" );
28
```

Array `args` stores command-line arguments

Check number of arguments passed in from the command line

Obtain first command-line argument

Obtain second and third command-line arguments

Calculate the value for each array element based on command-line arguments

Outline

```
29          // display array index and value
30          for ( int counter = 0; counter < array.length; counter++ )
31             System.out.printf( "%5d%8d\n", counter, array[ counter ] );
32       } // end else
33    } // end main
34 } // end class InitArray
```

```
java InitArray
Error: Please re-enter the entire command, including
an array size, initial value and increment.
```

Missing command-line arguments

```
java Ini
Index   Value
    0       0
    1       4
    2       8
    3      12
    4      16
```

Three command-line arguments are 5, 0 and 4

```
java InitArray 10 1 2
Index   Value
    0       1
    1       3
    2       5
    3       7
    4       9
    5      11
    6      13
    7      15
    8      17
    9      19
```

Three command-line arguments are 10, 1 and 2

InitArray.java

(2 of 2)

Program output

7.13 (Optional) GUI and Graphics Case Study: Drawing Arcs

- **Draw rainbow**
  - **Use arrays**
  - **Use repetition statement**
  - **Use `Graphics` method `fillArc`**

Outline

DrawRainbow

.java

(1 of 2)

Line 22

```
1  // Fig. 7.22: DrawRainbow.java
2  // Demonstrates using colors in an array.
3  import java.awt.Color;
4  import java.awt.Graphics;
5  import javax.swing.JPanel;
6
7  public class DrawRainbow extends JPanel
8  {
9     // Define indigo and violet
10    final Color VIOLET = new Color( 128, 0, 128 );
11    final Color INDIGO = new Color( 75, 0, 130 );
12
13    // colors to use in the rainbow, starting from the innermost
14    // The two white entries result in an empty arc in the center
15    private Color colors[] =
16       { Color.WHITE, Color.WHITE, VIOLET, INDIGO, Color.BLUE,
17         Color.GREEN, Color.YELLOW, Color.ORANGE, Color.RED };
18
19    // constructor
20    public DrawRainbow()
21    {
22       setBackground( Color.WHITE ); // set the background to white
23    } // end DrawRainbow constructor
24
25    // draws a rainbow using
26    public void paintComponent( Graphics g )
27    {
28       super.paintComponent( g );
29
30       int radius = 20; // radius of an arch
```

Set component background to white

```
31
32       // draw the rainbow near the bottom-center
33       int centerX = getWidth() / 2;
34       int centerY = getHeight() - 10;
35
36       // draws filled arcs starting with the outermost
37       for ( int counter = colors.length; counter > 0; counter-- )
38       {
39          // set the color for the current arc
40          g.setColor( colors[ counter - 1 ] );
41
42          // fill the arc from 0 to 180 degrees
43          g.fillArc( centerX - counter * radius,
44             centerY - counter * radius,
45             counter * radius * 2, counter * radius * 2, 0, 180 );
46       } // end for
47    } // end method paintComponent
48 } // end class DrawRainbow
```

Draw a filled semicircle

Outline

DrawRainbow

.java

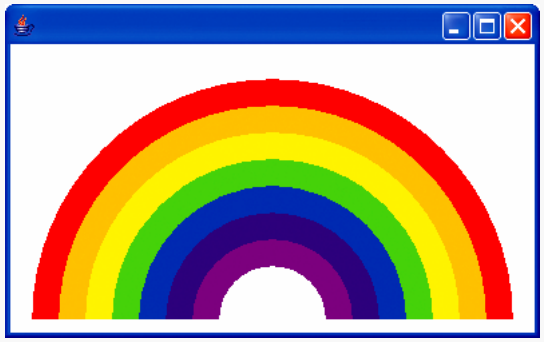
(2 of 2)

Lines 43-45

Outline

DrawRainbowTest.java

```
1  // Fig. 7.23: DrawRainbowTest.java
2  // Test application to display a rainbow.
3  import javax.swing.JFrame;
4
5  public class DrawRainbowTest
6  {
7     public static void main( String args[] )
8     {
9        DrawRainbow panel = new DrawRainbow();
10       JFrame application = new JFrame();
11
12       application.setDefaultCloseOperation( JFrame.EXIT_ON_CLOSE );
13       application.add( panel );
14       application.setSize( 400, 250 );
15       application.setVisible( true );
16    } // end main
17 } // end class DrawRainbowTest
```



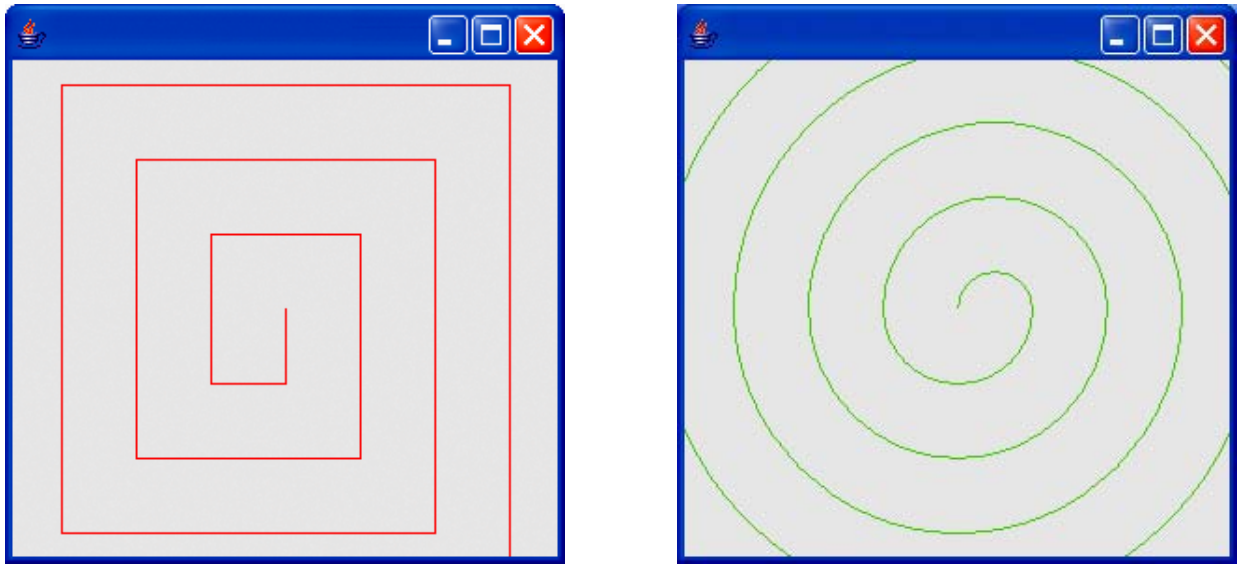


Fig. 7.24 | **Drawing a spiral using `drawLine` (left) and `drawArc` (right).**

7.14 (Optional) Software Engineering Case Study: Collaboration Among Objects

- **Collaborations**
  - **When objects communicate to accomplish task**
    - **Accomplished by invoking operations (methods)**
  - **One object sends a message to another object**

7.14 (Optional) Software Engineering Case Study (Cont.)

- **Identifying the collaborations in a system**
  - **Read requirements document to find**
    - **What ATM should do to authenticate a use**
    - **What ATM should do to perform transactions**
  - **For each action, decide**
    - **Which objects must interact**
      - **Sending object**
      - **Receiving object**

An object of class…	sends the message…	to an object of class…
ATM	displayMessage	Screen
	getInput	Keypad
	authenticateUser	BankDatabase
	execute	BalanceInquiry
	execute	Withdrawal
	Execute	Deposit
BalanceInquiry	getAvailableBalance	BankDatabase
	getTotalBalance	BankDatabase
	displayMessage	Screen
Withdrawal	displayMessage	Screen
	getInput	Keypad
	getAvailableBalance	BankDatabase
	isSufficientCashAvailable	CashDispenser
	debit	BankDatabase
	dispenseCash	CashDispenser
Deposit	displayMessage	Screen
	getInput	Keypad
	isEnvelopeReceived	DepositSlot
	Credit	BankDatabase
BankDatabase	validatePIN	Account
	getAvailableBalance	Account
	getTotalBalance	Account
	debit	Account
	Credit	Account

Fig. 7.25 | Collaborations in the ATM system.

7.14 (Optional) Software Engineering Case Study (Cont.)

- **Interaction Diagrams**
  - **Used to model interactions in the UML**
  - **Communication diagrams**
    - **Also called collaboration diagrams**
    - **Emphasize which objects participate in collaborations**
  - **Sequence diagrams**
    - **Emphasize when messages are sent between objects**

7.14 (Optional) Software Engineering Case Study (Cont.)

- **Communication diagrams**
  - **Objects**
    - **Modeled as rectangles**
    - **Contain names in the form `objectName : className`**
  - **Objects are connected with solid lines**
  - **Messages are passed alone these lines in the direction shown by arrows**
  - **Name of message appears next to the arrow**

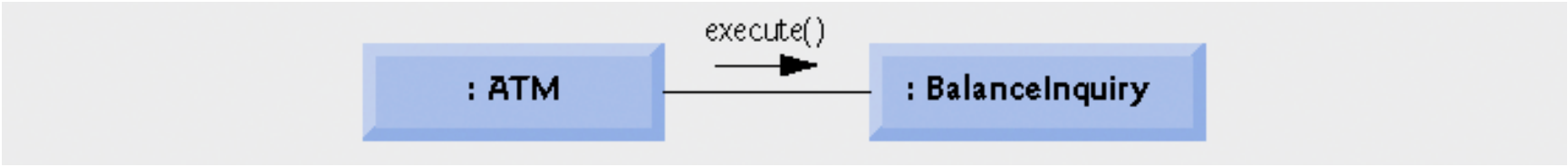


Fig. 7.26 | Communication diagram of the ATM executing a balance inquiry.

7.14 (Optional) Software Engineering Case Study (Cont.)

- **Sequence of messages in a communication diagram**
  - **Appear to the left of a message name**
  - **Indicate the order in which the message is passed**
  - **Process in numerical order from least to greatest**

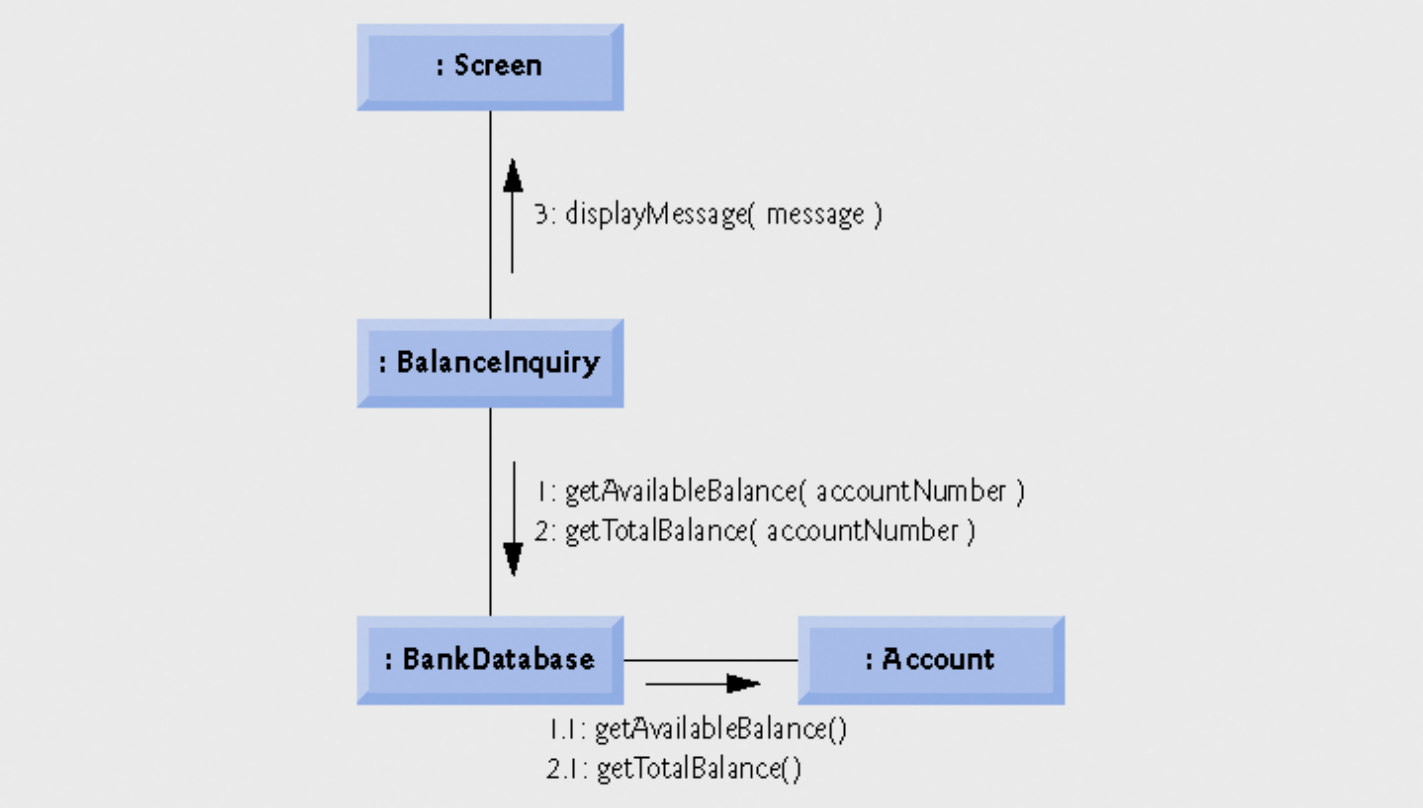


Fig. 7.27 | Communication diagram for executing a balance inquiry.

7.14 (Optional) Software Engineering Case Study (Cont.)

- **Sequence diagrams**
  - **Help model the timing of collaborations**
  - **Lifeline**
    - **Dotted line extending down from an object's rectangle**
      - **Represents the progression of time**
  - **Activation**
    - **Thin vertical rectangle**
      - **Indicates that an object is executing**

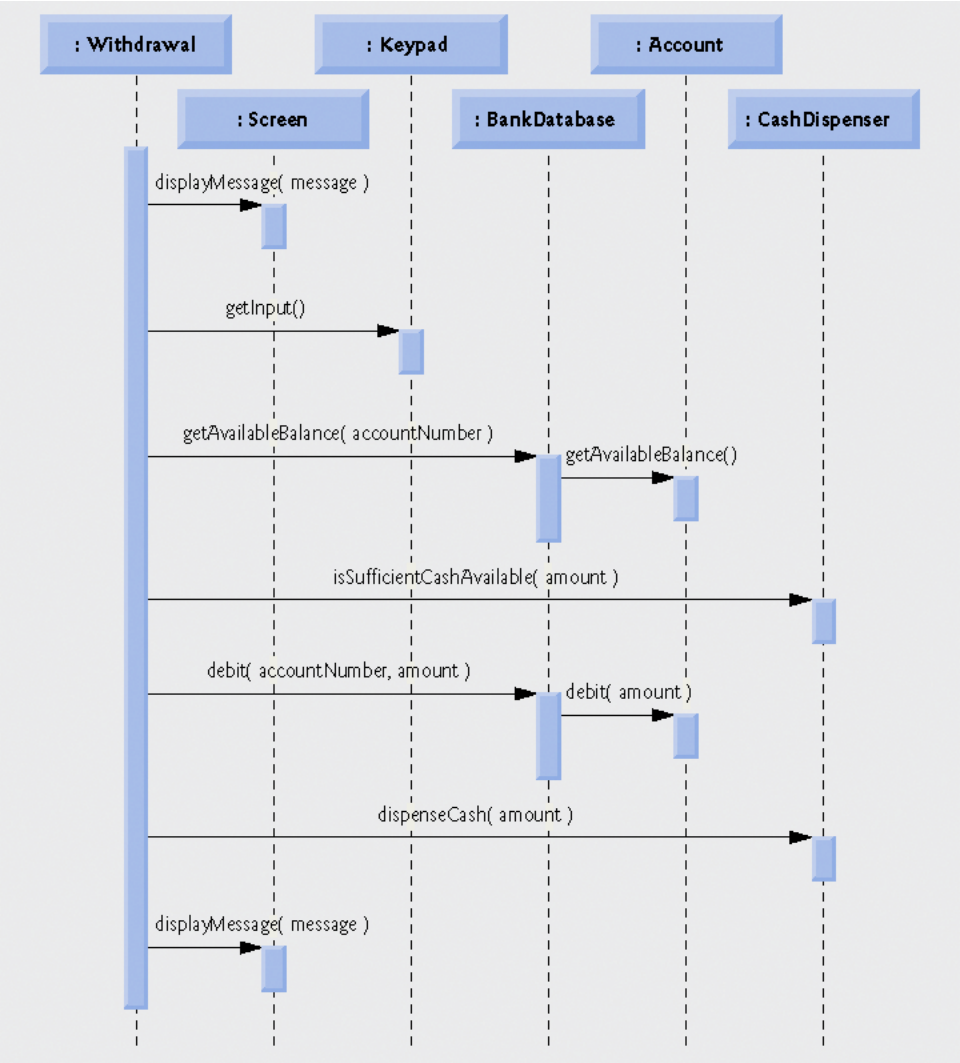


Fig. 7.28 | Sequence diagram that models a `Withdrawal` executing.

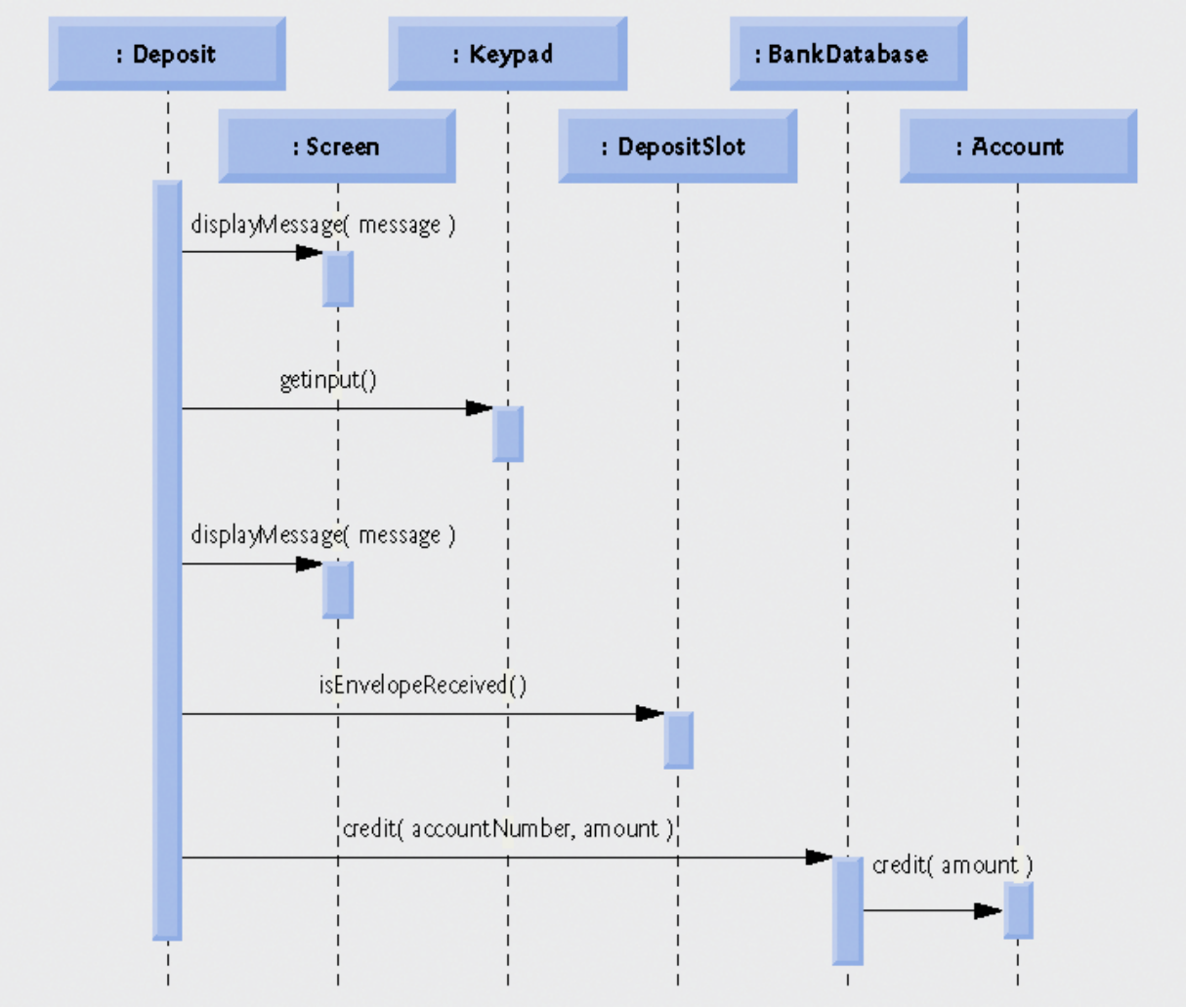


Fig. 7.29 | Sequence diagram that models a `Deposit` executing.