Chapter 7: Arrays
CS 121

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An array is an ordered list of values.

Each array has a name by which it can be referenced.

Each value (or element), of an array has a numeric index.
In Java, arrays are indexed from 0 to \( n - 1 \), where \( n \) is the number of elements in the array.

For example, our `scores` array has 5 elements that are indexed from 0 – 4.

Values stored in the same array must be of the same type – the element type.

The element type can be a primitive type (e.g. `int`, `double`, `boolean` etc.) or an object reference (e.g. `String`, `Song`, `Card`, etc.)

In Java, the array itself is an object that must be instantiated using the `new` operator.
Declaring Arrays

The scores array could be declared as follows.

- **LHS** – Declares the type of the scores variable as int[]. (meaning, an array of int values).
- **RHS** – Instantiates a new int[] (integer array) object of size 5.
Declaring Arrays

- An array of letters
  ```java
  char[] letters;
  letters = new char[26];
  ```

- An array of `String` objects
  ```java
  String[] dictionary = new String[480000];
  ```

- An array of `Song` objects
  ```java
  Song[] playlist = new Song[3];
  ```

- An array of `Card` objects
  ```java
  Card[] deckOfCards = new Card[52];
  ```

- An array of `boolean` objects
  ```java
  boolean[] lightSwitches = new boolean[100];
  ```
Accessing Array Elements

- A particular value in an array can be referenced using its index in the array.
- For example, to access the second element of our `scores` array, we would use the expression `scores[2]`.

```
scores[2]
```

- The value returned by the expression `scores[i]` is just an `int`. So, we can have expressions like,

```
totalScore += scores[2];
scores[2] = 89;  // Updates the value in the array
scores[count] = scores[count] + 2;
System.out.println("High score: " + scores[3]);
```

```
Typically, array elements are accessed using a for loop:

```java
// every array has a public constant called length // that stores the size of the array
int totalScore = 0;
for (int i = 0; i < scores.length; i++)
{
    totalScore += scores[i];
}
```

Or a for-each loop:

```java
int totalScore = 0;
for (int score: scores)
{
    totalScore += score;
}
```
/**
 * BasicArray.java - Demonstrates basic array declaration and use.
 * @author Java Foundations
 */

class BasicArray {

    /**
     * Creates an array, fills it with various integer values,
     * modifies one value, then prints them out.
     */
    public static void main(String[] args) {
        final int LIMIT = 15, MULTIPLE = 10;
        int[] list = new int[LIMIT];

        // Initialize the array values
        for (int index = 0; index < LIMIT; index++)
            list[index] = index * MULTIPLE;

        list[5] = 999; // change one array value

        // Print the array values
        for (int value: list)
            System.out.print(value + " ");
    }
}
Using Arrays: Example

The array is created with 15 elements, indexed from 0 to 14.

After three iterations of the first loop:

After completing the first loop:

After changing the value of list[5]:

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When an array is created, it has a fixed size. The size of the array is provided by a public constant named \texttt{length}.

When accessing an element of an array, we must use a valid index. For example, for an array \texttt{scores}, the range of valid indexes is \texttt{0} to \texttt{scores.length - 1}.

What happens when we try to access something out of bounds? The Java interpreter throws an \texttt{ArrayIndexOutOfBoundsException}.

This is called automatic bounds checking.
Recall our scores array. The valid index range is 0 to 4.

Now, we want to print all values in our array using this loop:

```java
for (int i = 0; i <= scores.length; i++) {
    System.out.println(scores[i]);
}
```

Will this work? **NO. The last iteration of our loop is trying to access the element at index 5. But it doesn’t exist!**

We will get an exception...

```java
ScoresArray 10 20 30 40 50 Exception in thread "main" java.
lang.ArrayIndexOutOfBoundsException: 5
at ScoresArray.main(ScoresArray.java:10)
```
 Bounds Checking

- **Off-by-one** errors are common when using arrays.
- Remember, the `length` constant stores the size of the array, not the largest index.
- The correct loop condition is

```java
for(int i = 0; i < scores.length; i++) {
    System.out.println(scores[i]);
}
```
Examples

- Example: ReverseOrder.java
  - Reads a list of numbers from a user and prints it in the opposite order.

- Example: LetterCount.java
  - Reads a sentence and prints the counts of lowercase and uppercase letters.
In-class Exercise

- Write an array declaration for the ages of 100 children.
- Write a for loop to print the ages of the children
- Write a for-each loop to print the ages of the children
- Write a for loop to find the average age of these children, assuming that the array has been initialized.
What does the following code do?

```java
int[] array = new int[100];
for (int i = 0; i < array.length; i++)
    array[i] = 1;

int[] temp = new int[200];
for (int i = 0; i < array.length; i++)
    temp[i] = array[i];
```

What happens if we now assign `temp` to `array`?

```java
array = temp;
```
The name of an array is an object reference variable:

An array of objects really just holds object references. For example, the following declaration reserves space to store 5 references to `String` objects.

```java
String[] words = new String[5];
```

It does not create the `String` objects themselves.

Initially, the array holds `null` references. We need to create the `String` objects.
Arrays of Objects (2)

- After declaration.

```java
String[] words = new String[5];
```

- After adding 3 strings.

```java
words[0] = "friendship";
words[1] = "loyalty";
words[2] = "honor";
```
Arrays of Objects (3)

- An array of coins.

```java
Coin[] wallet = new Coin[5];
for (int i = 0; i < wallet.length; i++)
    wallet[i] = new Coin();
```

- A collection of a hundred random die.

```java
Random rand = new Random();
Die[] diceCollection = new Die[100];
for (int i = 0; i < diceCollection.length; i++) {
    int numFaces = rand.nextInt(20) + 1;
    diceCollection[i] = new Die(numFaces);
}
```
Example: CD.java, CDCollection.java, Tunes.java
The size of an array is fixed at the time of creation. What if the array fills up and we want to add more elements? We can create a new array and copy the existing elements to the new array. In effect, we have grown the array. How much bigger should the new array be?

- **Minimum space**: We could grow the array by one element so it can store the new element.
- **Minimum time**: Grow the array to the maximum size we will ever need. However, in many cases we don’t know ahead of time how large the array needs to grow.
- **Heuristic**: A good heuristic is to double the size so we don’t have to do the copying again and again.

The **ArrayList** class grows an array internally. **Example**: GrowingArrays.java
In-class Exercise

▶ Declare and instantiate an array of hundred Color objects.

```
Color[] myColors = new Color[100];
```

▶ Now fill the array with random colors using a for loop.

```
Random rand = new Random();
for (int i = 0; i < myColors.length; i++) {
    myColors[i] = new Color(rand.nextInt(256),
                            rand.nextInt(256),
                            rand.nextInt(256));
}
```

▶ Write an array declaration and any necessary supporting classes to represent credit card transactions that contain a transaction number, a merchant name, and a charge.

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Initializing Arrays

- An **initializer list** can be used to instantiate and fill an array in one step.

- For example,

  ```java
  int[] scores = {91, 82, 78, 98, 86};
  String[] fruit = {"apple", "orange", "banana"};
  ```

- The `new` operator is not needed (it is implied).

- The **size** of the new array is determined by the number of items in the initializer list.

- Initializer lists can only be used in the array declaration.

- Initializer lists can contain expressions or objects (including calls to `new` to create objects). For example:

  ```java
  Die[] myCollection = {new Die(10), new Die(20), new Die(20)};
  ```
An entire array can be passed as a parameter to a method. Like any other object, the reference to the array is passed, making the formal and actual parameters aliases of each other. Therefore, changing an array element within the method changes the original outside of the method. An individual array element can be passed to a method as well, in which case the type of the formal parameter is the same as the element type. Example: ArrayPassing.java
A program can accept any number of arguments from the command line (known as command-line arguments).

Allows the user to specify configuration information when the program is launched, instead of asking for it at run-time.

For example, suppose a Java application called `Sort` sorts lines in a file. To sort the data in a file named `friends.txt`, a user would enter:

```java
java Sort friends.txt
```
Recall: The `main` method takes an array of `String` objects as a parameter.

```java
public static void main(String[] args) { ... }
```

When an application is launched, the runtime system passes the command-line arguments to the application’s `main` method via this array of `String` objects.

In our previous example, the `String` array passed to the `main` method of the `Sort` application contains a single `String`: "friends.txt".
The following program prints each element of the `args` array to the console.

```java
public class CommandLineEcho {
    public static void main(String[] args) {
        for (String arg : args) {
            System.out.println(arg);
        }
    }
}
```

If we execute the program as follows

```sh
done CommandLineEcho monkey peanut banana
```

We would get

```
monkey
peanut
banana
```
Note that the space character separates command-line arguments.

To have all words interpreted as a single argument, we can enclose them in quotation marks.

```
java CommandLineEcho "monkey peanut banana"
```

Would give us

```
monkey peanut banana
```
We always want to validate our command-line arguments and print an appropriate usage message to the user if they entered invalid arguments.

Typically, we want to validate:
- the number of arguments
- the type of arguments
- the values are within a specific range

Let’s say we have a program that accepts a filename (String) followed by the number of characters per line (int). The number of characters per line must be between 1 and 80.

Example: CommandLineValidation.java
In many cases, our command-line arguments will need to support numeric arguments.

To handle this, we need to convert a String argument to a numeric value.

```java
int firstArg;
if (args.length > 0) {
    try {
        firstArg = Integer.parseInt(args[0]);
    } catch (NumberFormatException e) {
        System.err.println("Argument " + args[0] + " must be an integer.");
        System.exit(1);
    }
}
```

parseInt throws a NumberFormatException if the format of args[0] isn’t valid.

All of the wrapper classes for primitive types have parseX methods that convert a String representing a number to an object of their type X.
2-Dimensional Arrays

- A one-dimensional array stores a list of elements.
- A two-dimensional array can be thought of as a table of elements, with rows and columns.
In Java, a 2-D array is an array of arrays. A 2-D array is declared by specifying the size of each dimension separately.

```java
int[][] table = new int[3][5];
```

An array element is referenced using two index values:

```java
int value = table[1][3];
```

Note that `table.length` is the number of rows in the table.

Note that `table[i].length` is the length of the `i`th row in the table.
2-Dimensional Arrays (2)

- **In-class Exercise.** What does the following 2-d array contain after the code executes?

```java
int numRows = 3, numCols = 5;
int[][] table = new int[numRows][numCols];
for (int row = 0; row < numRows; row++)
    for (int col = 0; col < numCols; col++)
        table[row][col] = row;
```

- **In-class Exercise.** What if we change the initialization?

```java
for (int row = 0; row < numRows; row++)
    for (int col = 0; col < numCols; col++)
        table[row][col] = row * numCols + col;
```
In-class Exercise. What does the following method do?

```java
public static void printArray (int arr[][]) {
    for (int i = 0; i < arr.length; i++) {
        for (int j = 0; j < arr[i].length; j++)
            System.out.print(arr[i][j] + " ");
        System.out.println();
    }
    System.out.println();
}
```

Example: TwoDimArrays.java
Since a 2-dimensional array is an *array of arrays*, we can declare it in two parts:

```java
int[][] table = new table[3][]; // 2nd dim blank
for (int i = 0; i < table.length; i++)
    table[i] = new int[5];
```

- **Layout of a 2-dim array in memory:**

![Diagram of 2-dimensional array layout](image)
Two-dimensional arrays don’t have to be square or rectangular in shape!

Example: FunkyArrays.java

In-class Exercise What does the following code do?

```java
Color[][] board = new Color[8][8];
for (int row = 0; row < board.length; row++) {
    for (int col = 0; col < board[row].length; col++) {
        if (row % 2 == col % 2)
            board[row][col] = Color.white;
        else
            board[row][col] = Color.red;
    }
}
```
Multi-Dimensional Arrays (1)

- Any array with more than one dimension is a **multi-dimensional array**.
- Each dimension subdivides the previous one into the specified number of elements.
- Each dimension has its own length constant.
- Because each dimension is an array of array references, the arrays within one dimension can be of different lengths.
Arrays can have more than two-dimensions. Here is a declaration for a 3-dimensional array.

```java
double[][][] data = new double[4][1000][100];
```

Can you think of when a 3-D array might be useful?
- A spreadsheet is a 2-dimensional array. The tabs would make it 3-dimensional.
- Simulations of liquids, solids, space etc.
- Modeling in science and engineering.

A 4-D array? (not very common...)

Instead of building larger dimensional arrays, it is a better design to have arrays of objects such that the objects contain arrays inside them as needed to get the dimensional depth.
Multi-Dimensional Arrays (3)

- Consider a 3-dim array to represent a universe that has a 100 galaxies. Suppose that each galaxy has a 1000 star clusters. Each cluster has 10 stars.

```java
Star[][][] myUniverse = new Star[100][1000][10];
```

```java
public class Star {
    ...
}
```

- Here is a different design that avoids the multidimensional array.

```java
Galaxy[] myUniverse = new Galaxy[100];
```

```java
public class Galaxy {
    private Cluster[] myClusters = new Cluster[1000];
    // other related instance variables
}
```

```java
public class Cluster {
    private Star[] myStars = new Star[10];
    // other related instance variables
}
```

```java
public class Star {
    ...
}
```
In-class Exercise

How would we implement an `ArrayList<String>`? How would we implement the following operations?

- `add(String element)`: adds an element to the end of the array list
- `add(String element, int index)`: adds an element at the \( i \)th position
- `remove(int index)`: removes an element at the \( i \)th position
- `contains(String s)`: returns true if the array list contains the string \( s \)
Exercises

▶ Read Chapter 7 (skip Section 7.5).
▶ **Recommended Homework:**
  ▶ Exercises: EX 7.1, 7.4 (e), 7.5, 7.8.
  ▶ Projects: PP 7.1, 7.2, 7.5.
▶ Browse: Sections 6.1.