香港中文大學(深圳)
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CSC3100 Data Structures
Lecture 3: Array

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Outline

- Concepts on arrays
- ADT of Arrays
- Implementation
- Examples

Array

- An array is used to store the same type of objects together, and access the objects by their indices
  - Pro: If you know the index (where), you can find the object (content) with one basic operation (efficient). Efficient search if array is sorted
  - Con: (i) If you want to insert an object in a place between two objects in an array, you have to move the objects first; (ii) The capacity is fixed

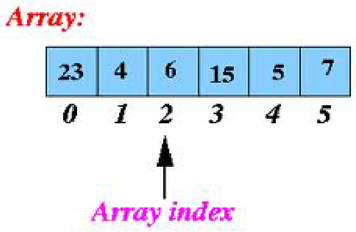
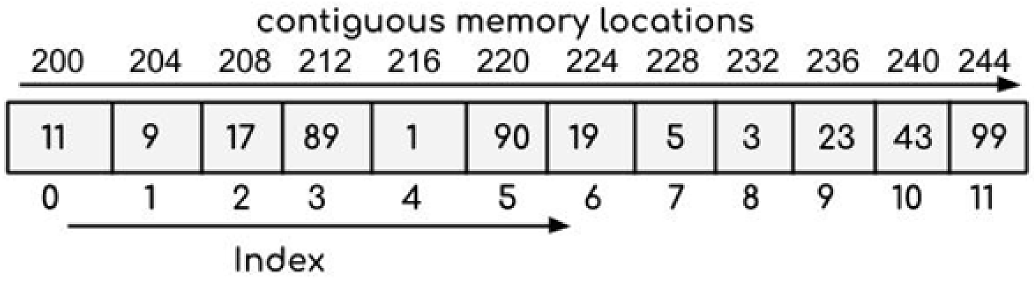


Illustration from wikipedia

- Array: a data structure consisting of a collection of elements (values or variables)
    - Each element is identified by at least one array index or key
    - The memory position of each element can be computed from its index tuple
    - The simplest type of data structure is a linear array, also called one-dimensional array

- More introduction
    - Arrays are among the oldest and most important data structures, and are used by almost every program
    - The simplest type of array is a linear array, or one-dimensional array; arrays are used for representing vectors/matrices
    - The memory address of the first element of an array is called first address, foundation address, or base address

Concepts



- Array: An ordered collection of values
  - Ordered and fixed length
  - Homogeneous: each value in the array is of the same type

- The individual values in an array are called **elements**

- The number of elements is called the **length** of the array

- Each element is identified by its position in the array, which is called **index**
  - In Java, the index numbers begin with 0

Array ADT

```
ADT Array
 Array createArray(n)
 Item retrieve(arr, i)
 Item store(arr, i, itemToStore)
```

- createArray(n)
  - Initialized an array of size n to store item
- retrieve(arr,i)
  - arr[i],
  - Return the item stored in the i-th position of the array
- store(arr, i, itemToStore)
  - Store itemToStore to the i-th position of the array
  - arr[i] = itemToStore

Advantage of ADT

- We can design algorithms without knowing its underlying implementation
  - E.g., design an algorithm to do linear search with an array using ADT

Algorithm 1: ***Linear Search***
Input: An array *a* of integers with length n, an integer searchnum
Output: the index i such that the value stored in the i-th position equals searchnum , or -1 if no such i exists

```
int i;
for (i=0; i<n; i++){
    if( retrieve(a,i) == searchnum )
        return i;
}
return -1;
```

Array ADT: example

- We can design algorithms without knowing its underlying implementation
  - E.g., implement the dimension-product given two arrays a_1 and a_2 and output to a_3 such that $a_3[i] = a_1[i] \cdot a_2[i]$

Algorithm 2: ***Dimension Product***
Input: Vector a_1, a_2, a_3 of length n
Output: Dimension-product of a_1 and a_2 which stored in a_3

```
int i,i_dimension_coordinate;
for (i=0; i<n; i++){
        i_dimension_coordinate = retrieve(a₁,i)*retrieve(a₂,i);
         store(a₃, i, i_dimension_coordinate);
}
return a₃;
```

Java: array declaration

- An array is characterized by
  - Element type
  - Length: type[ ] identifier = new type[length];
- Default values in initialization

numerics	0
boolean	false
objects	null

Elements of an array can be objects of any Java class

Example: An array of 5 instances of the student class

```
Student [ ]
topStudents = new Student[5];
```

Java: array operations

- Use named constant to declare the length of an array, or read the length of an array from the user

```
private static final int N_JUDGES = 5;
double[ ] scores = new double[N_JUDGES];
```

- Identifying an element: array[index]

- Index can be an expression, e.g., array[(a+b)/2]

- Cycling through array elements

```
for (int i = 0; i < array.length; i++) {
        operations involving the ith element;
}
```

Array initialization

- A convenient way of initializing an array:

```
int[ ] digits = {0, 1, 2, 3, 4, 5, 6, 7, 8, 9};

String[ ] US_CITIES_OVER_ONE_MILLION = {
   "New York",
   "Los Angeles",
   "Chicago",
   "Huston",
   "Philadelphia",
   "Phoenix",
   "San Diego",
   "San Antonio",
   "Dallas",
}
```

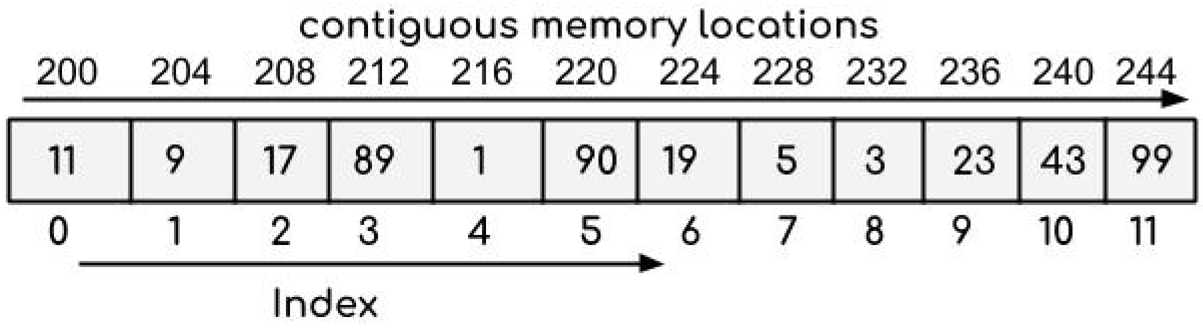
Human-readable index values

- Starting index numbering at 0 can be confusing
  - Sometimes, it makes sense to work with index that begins with 1

- Two standard ways:
  - Use Java's index number internally and then add one when presenting to the user
  - Use index values beginning at 1 and ignore the first (0) element in each array

Internal representation

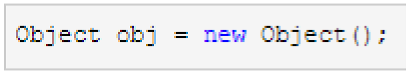
- A (memory) array is a linear data structure that hosts a collection of similar data types stored at consecutive locations in a computer's memory
  - If we have the base address (the address of the first element), the address of other elements can be then calculated using the base address



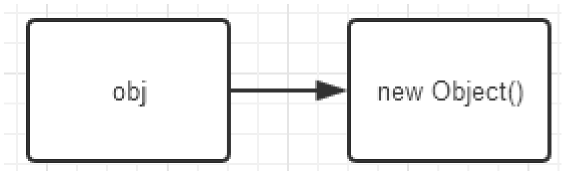
Pass-by-Value vs Pass-by-Reference

swapElements(array[i], array[n – i – 1]) [wrong]
swapElements(array, i, n – i – 1)

- What is Pass-by-Value?
  - The value of a function parameter is copied to another location of the memory
  - When accessing or modifying the variable within the function, it accesses only the copy, so there is no effect on the original value
- What is Pass-by-Reference?
  - The memory address is passed to that function, so the function gets access to the actual variable



```
Object obj = new Object();
```

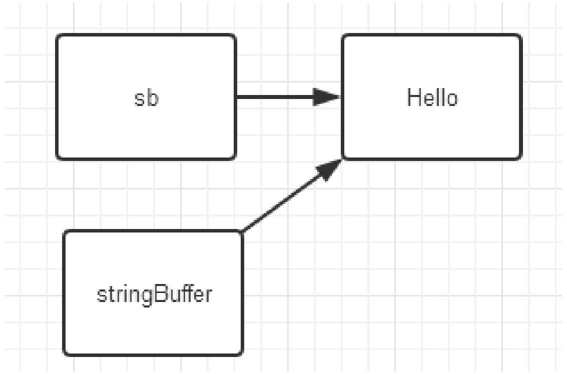


Examples

```
public class test {
    public static void main(String[] args) {
        int i = 1;
        System.out.println("before change, i = "+i);
        change(i);
        System.out.println("after change, i = "+i);
    }
    public static void change(int i){
        i = 5;
    }
}
```

```
before change, i = 1
after change, i = 1
```

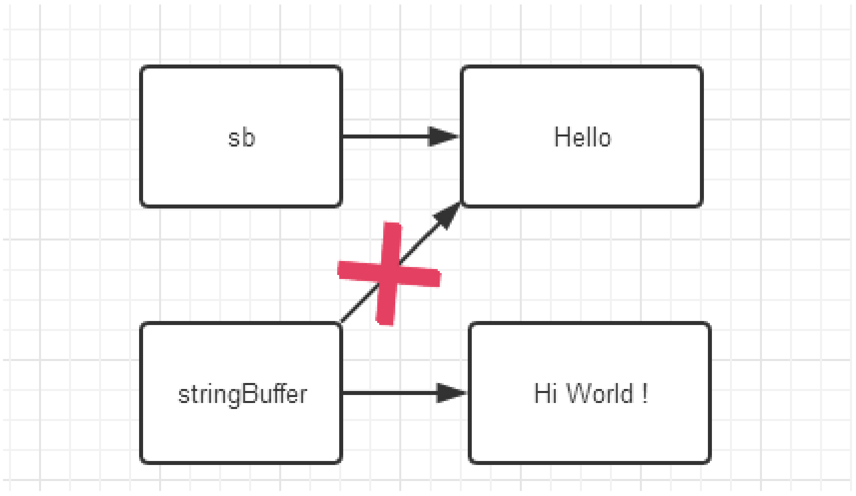
```
public class test {
    public static void main(String[] args) {
        StringBuffer sb = new StringBuffer("Hello ");
        System.out.println("before change, sb is "+sb.toString());
        change(sb);
        System.out.println("after change, sb is "+sb.toString());
    }
    public static void change(StringBuffer stringBuffer){
        stringBuffer.append("world !");
    }
}
```



```
before change, sb is Hello
after change, sb is Hello world !
```

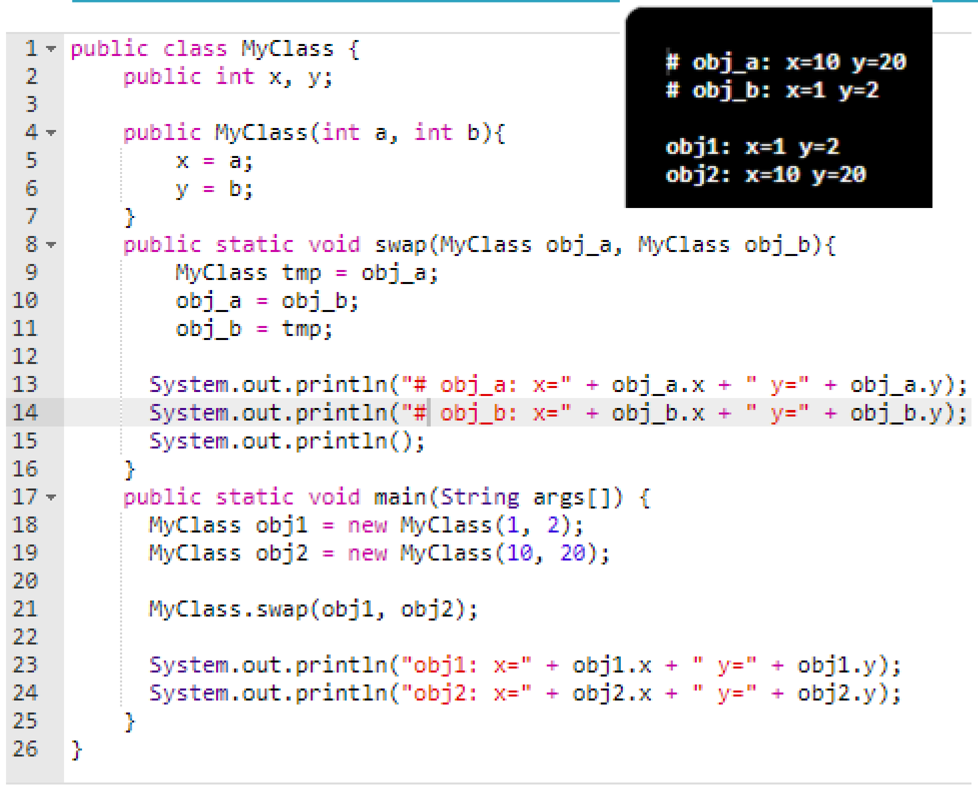
Examples

```
public class test {
    public static void main(String[] args) {
        StringBuffer sb = new StringBuffer("Hello ");
        System.out.println("before change, sb is "+sb.toString());
        change(sb);
        System.out.println("after change, sb is "+sb.toString());
    }
    public static void change(StringBuffer stringBuffer){
        stringBuffer = new StringBuffer("Hi ");
        stringBuffer.append("world !");
    }
}
```



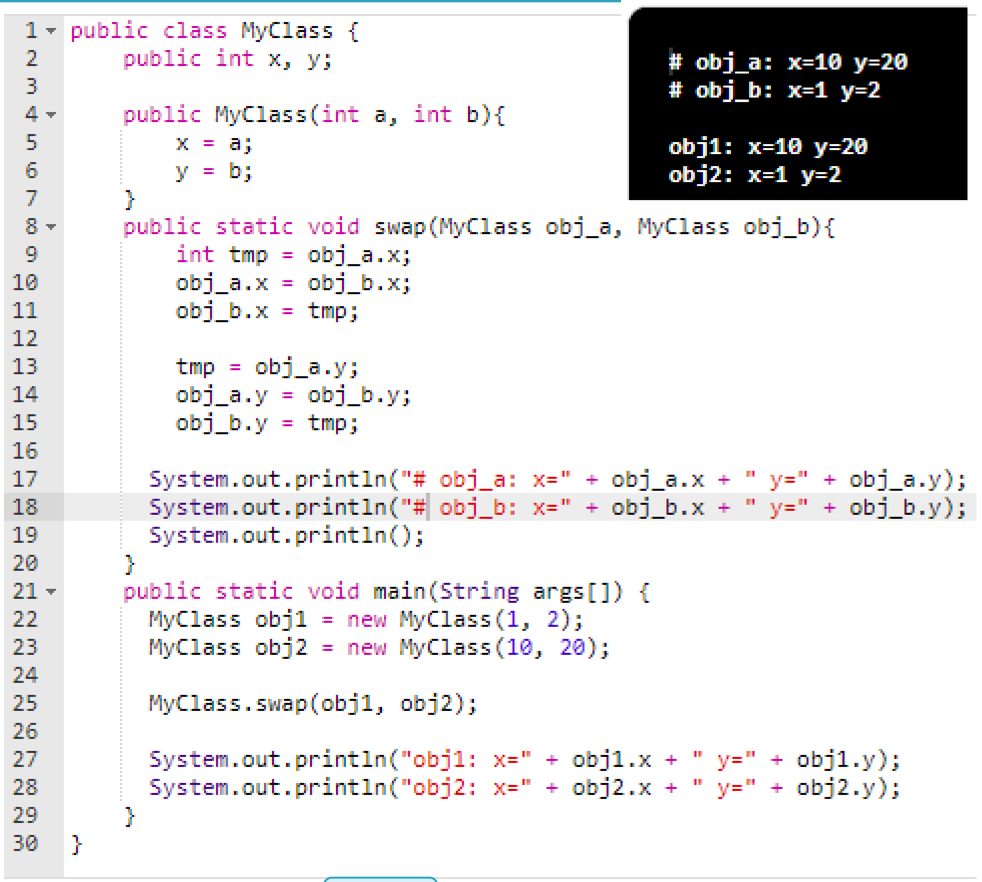
```
before change, sb is Hello
after change, sb is Hello
```

Examples



```
public class MyClass {
    public int x, y;

    public MyClass(int a, int b){
        x = a;
        y = b;
    }
    public static void swap(MyClass obj_a, MyClass obj_b){
        MyClass tmp = obj_a;
        obj_a = obj_b;
        obj_b = tmp;

      System.out.println("# obj_a: x=" + obj_a.x + " y=" + obj_a.y);
      System.out.println("# obj_b: x=" + obj_b.x + " y=" + obj_b.y);
      System.out.println();
    }
    public static void main(String args[]) {
      MyClass obj1 = new MyClass(1, 2);
      MyClass obj2 = new MyClass(10, 20);

      MyClass.swap(obj1, obj2);

      System.out.println("obj1: x=" + obj1.x + " y=" + obj1.y);
      System.out.println("obj2: x=" + obj2.x + " y=" + obj2.y);
    }
}
```

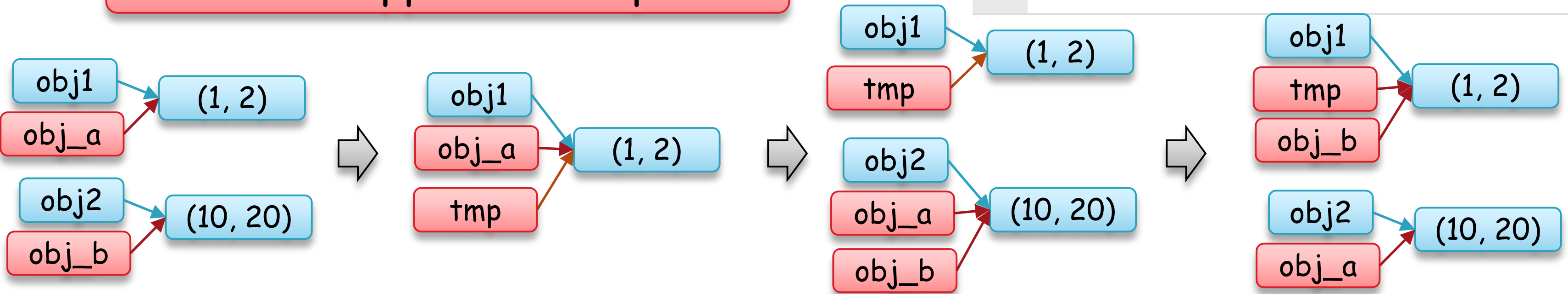
```
# obj_a: x=10 y=20
# obj_b: x=1 y=2

obj1: x=1 y=2
obj2: x=10 y=20
```



```
public class MyClass {
    public int x, y;

    public MyClass(int a, int b){
        x = a;
        y = b;
    }
    public static void swap(MyClass obj_a, MyClass obj_b){
        int tmp = obj_a.x;
        obj_a.x = obj_b.x;
        obj_b.x = tmp;

        tmp = obj_a.y;
        obj_a.y = obj_b.y;
        obj_b.y = tmp;

      System.out.println("# obj_a: x=" + obj_a.x + " y=" + obj_a.y);
      System.out.println("# obj_b: x=" + obj_b.x + " y=" + obj_b.y);
      System.out.println();
    }
    public static void main(String args[]) {
      MyClass obj1 = new MyClass(1, 2);
      MyClass obj2 = new MyClass(10, 20);

      MyClass.swap(obj1, obj2);

      System.out.println("obj1: x=" + obj1.x + " y=" + obj1.y);
      System.out.println("obj2: x=" + obj2.x + " y=" + obj2.y);
    }
}
```

```
# obj_a: x=10 y=20
# obj_b: x=1 y=2

obj1: x=10 y=20
obj2: x=1 y=2
```

What happens in swap ?



Passing arrays as parameters

```
private void swapElements(int[] array, int p1, int p2) {
        int  tmp = array[p1];
        array[p1] = array[p2];
        array[p2] = tmp;
}
```

- Every array in Java has a length field

```
private void reverseArray(int[] array)  {
        for (int  i = 0; i < array.length / 2; i++) {
                swapElements(array, i, array.length - i - 1);
        }
}
```

Exercise: using arrays

- Letter frequency table:
  - Given an array of letters,

    e.g., A[ ]={'A', 'B', 'C', 'B', 'A'}

    count the frequency of each letter

- Can you design a fast algorithm to solve the above problem?

Maximum number of elements

- What's the maximum number of elements in a Java array?
  - Integer.MAX_VALUE
- How to use an array to store a set of elements whose size is larger than the maximum number of elements in Java array?
  - Multi-dimensional array

Two-dimensional arrays

- Each element of an array is an array (of the same dimension)
  - E.g., a 3-by-2 matrix

```
int[][] A = new int[3][2];
int A[3][2] =  { {1,  4},  {2,  5}, {3,  6}};
```

- An array of three arrays of dimension two

```
A[0][0] A[0][1]
A[1][0] A[1][1]
A[2][0] A[2][0]
```

The ArrayList Class

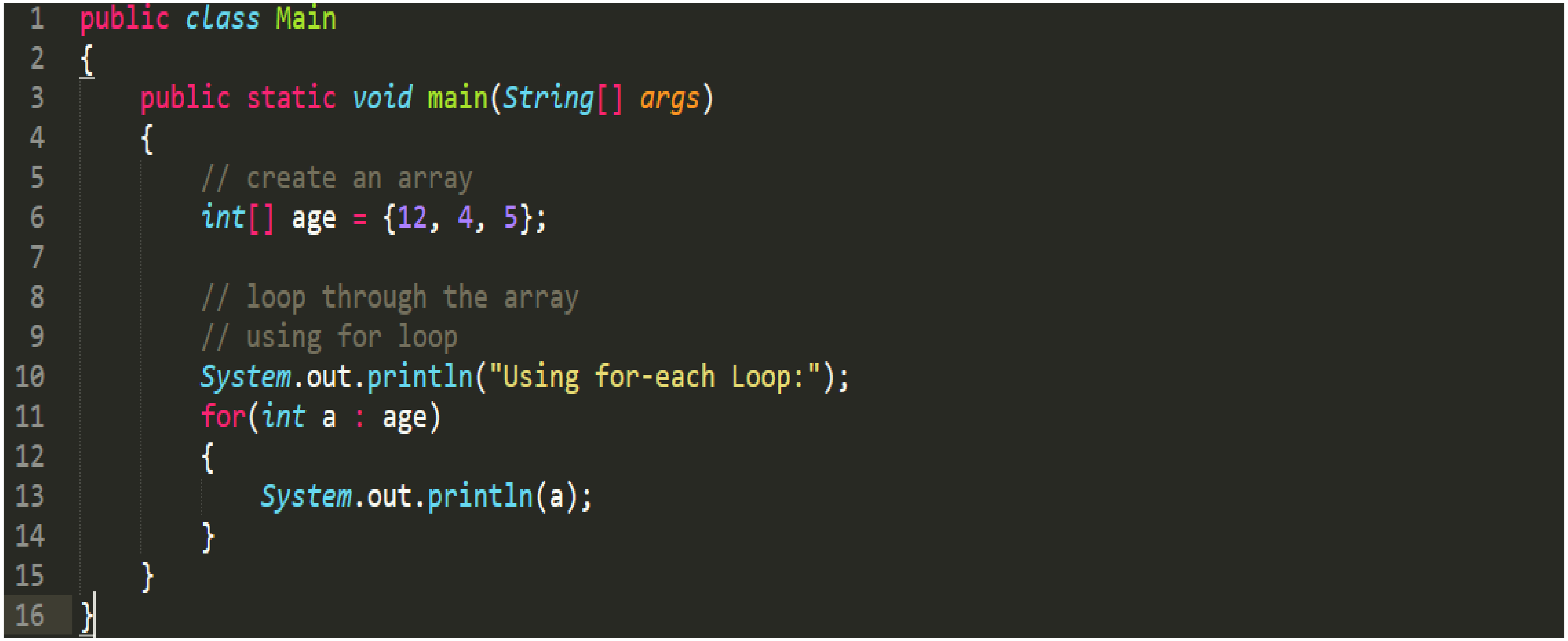
- The **java.util** package has a class called **ArrayList**
  - Provide standard array behaviors along with other useful operations
  - **ArrayList** is a Java class rather than a special form in the language;

- All operations on **ArrayLists** are indicated using method calls
  - Create a new **ArrayList** by calling **ArrayList** constructor
  - Get the number of elements by calling the **size** method
  - Use the **get** and **set** methods to select individual elements

https://docs.oracle.com/javase/8/docs/api/java/util/ArrayList.html

More examples in Java

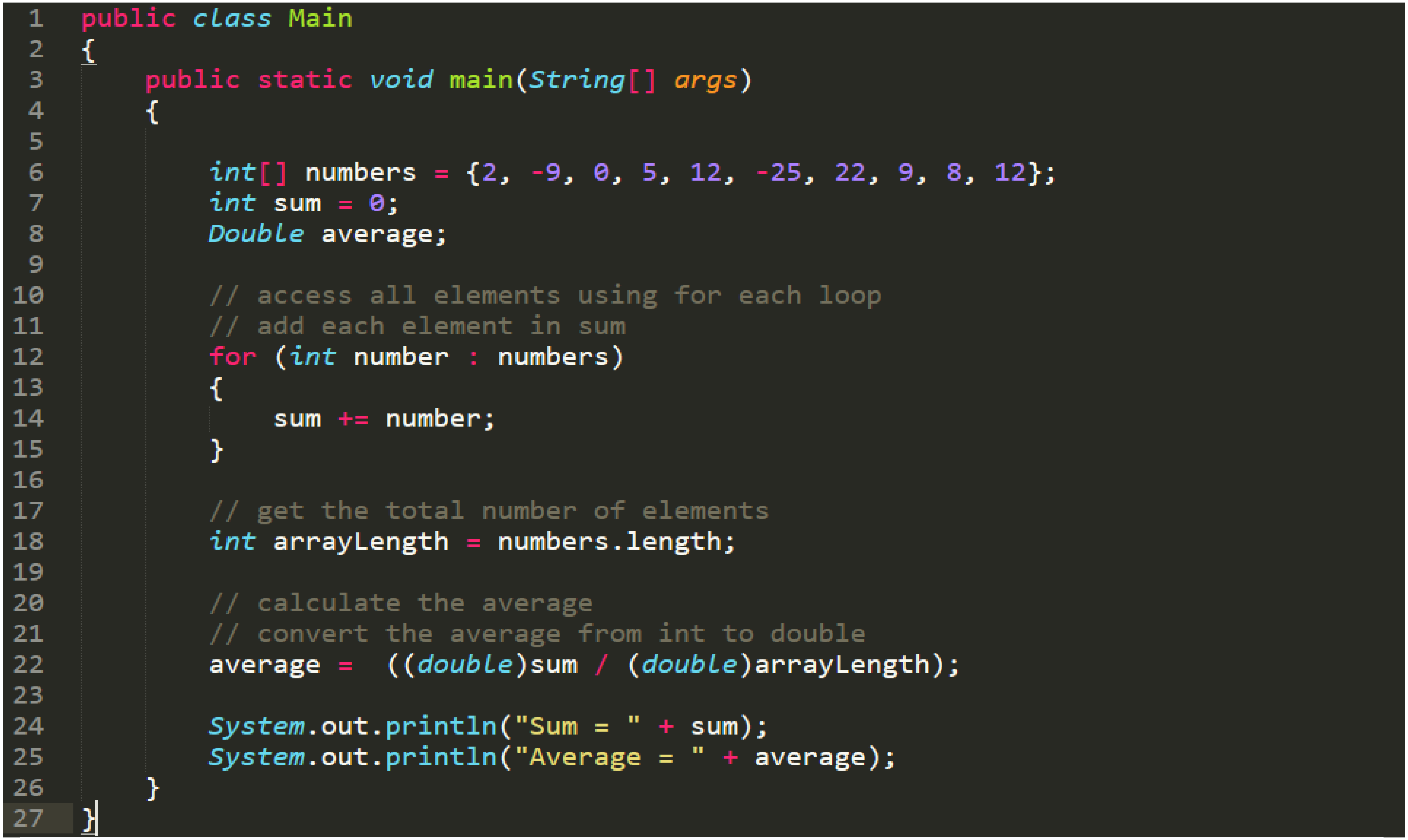
- Number arrays
  - int, float, double, …
- String arrays
- Boolean arrays



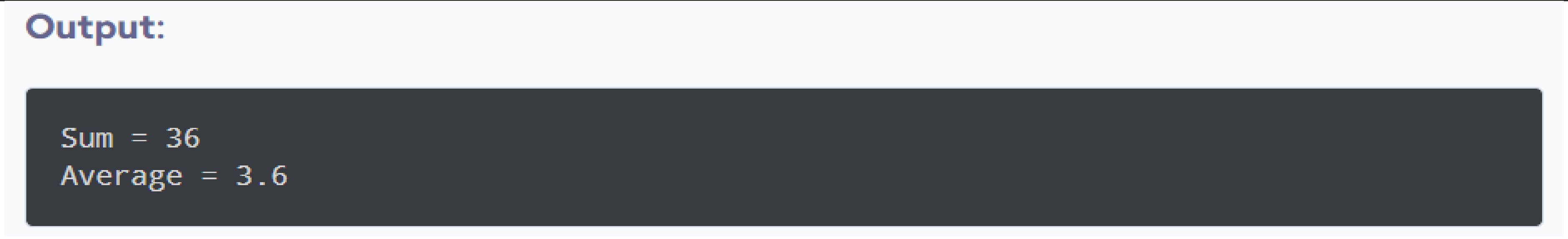
```java
public class Main
{
    public static void main(String[] args)
    {
        // create an array
        int[] age = {12, 4, 5};

        // loop through the array
        // using for loop
        System.out.println("Using for-each Loop:");
        for(int a : age)
        {
            System.out.println(a);
        }
    }
}
```

Output

```
Using for-each Loop:
12
4
5
```

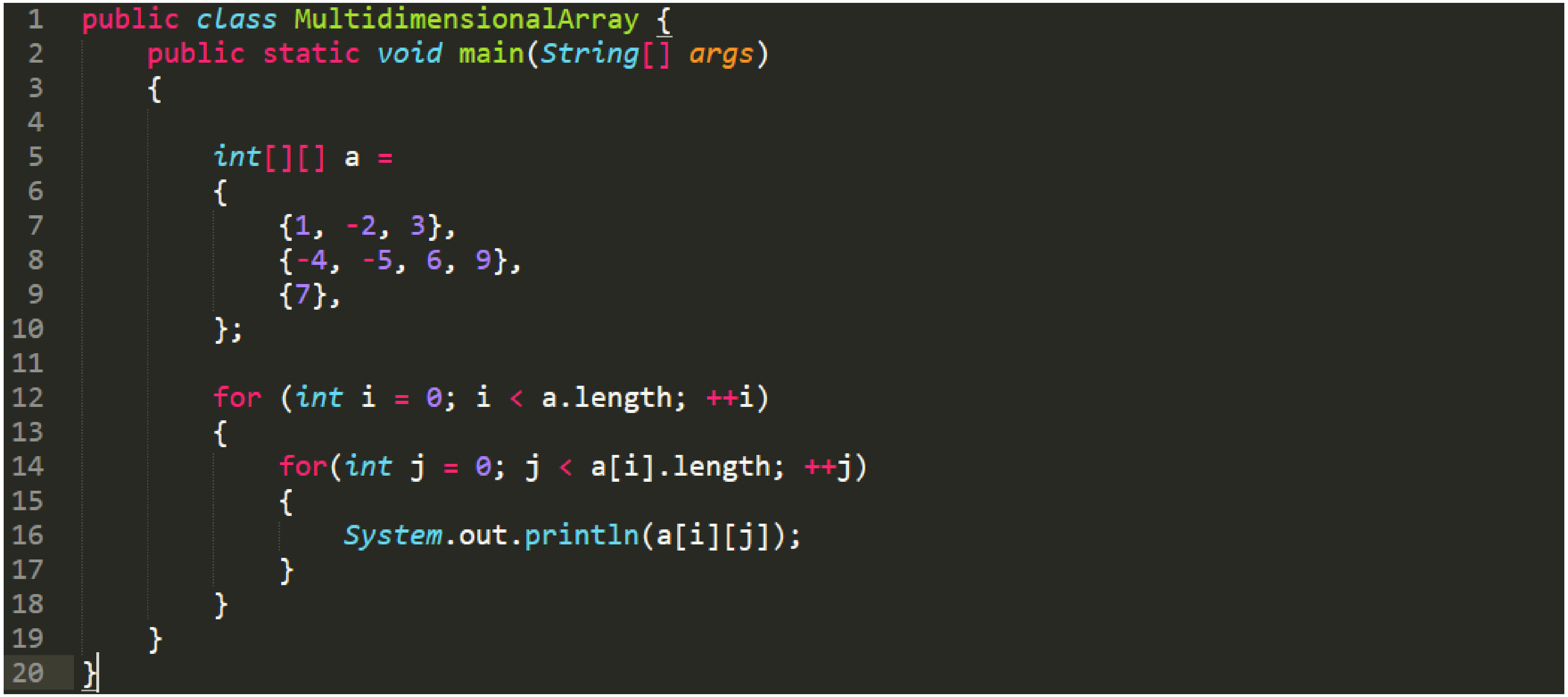


```java
public class Main
{
    public static void main(String[] args)
    {

        int[] numbers = {2, -9, 0, 5, 12, -25, 22, 9, 8, 12};
        int sum = 0;
        Double average;

        // access all elements using for each loop
        // add each element in sum
        for (int number : numbers)
        {
            sum += number;
        }

        // get the total number of elements
        int arrayLength = numbers.length;

        // calculate the average
        // convert the average from int to double
        average =  ((double)sum / (double)arrayLength);

        System.out.println("Sum = " + sum);
        System.out.println("Average = " + average);
    }
}
```

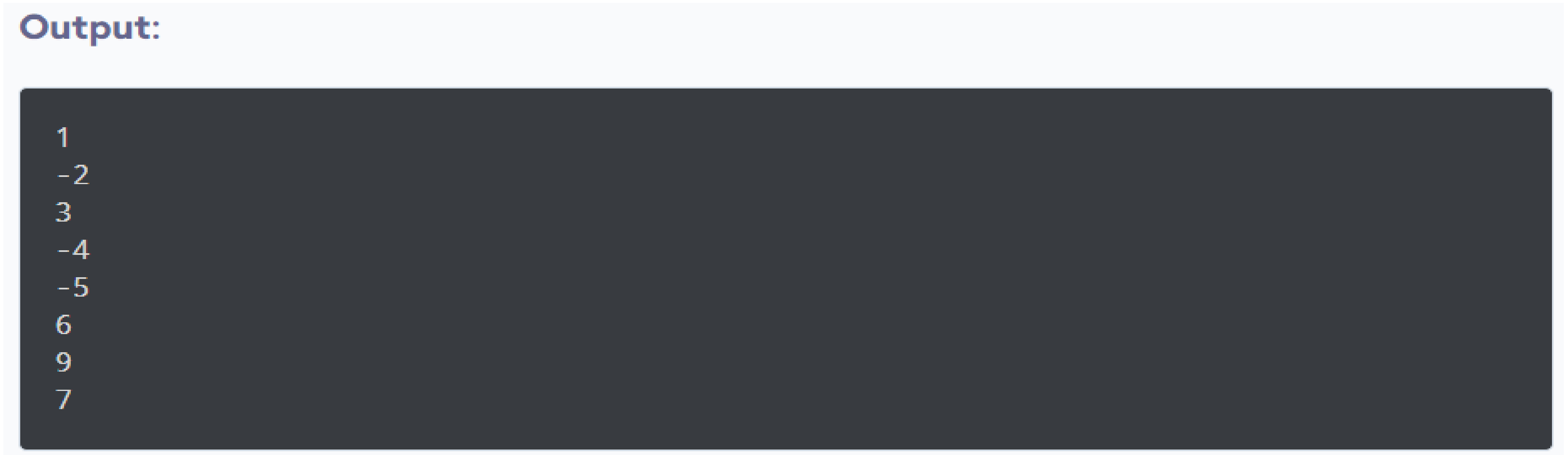


Output:

```
Sum = 36
Average = 3.6
```

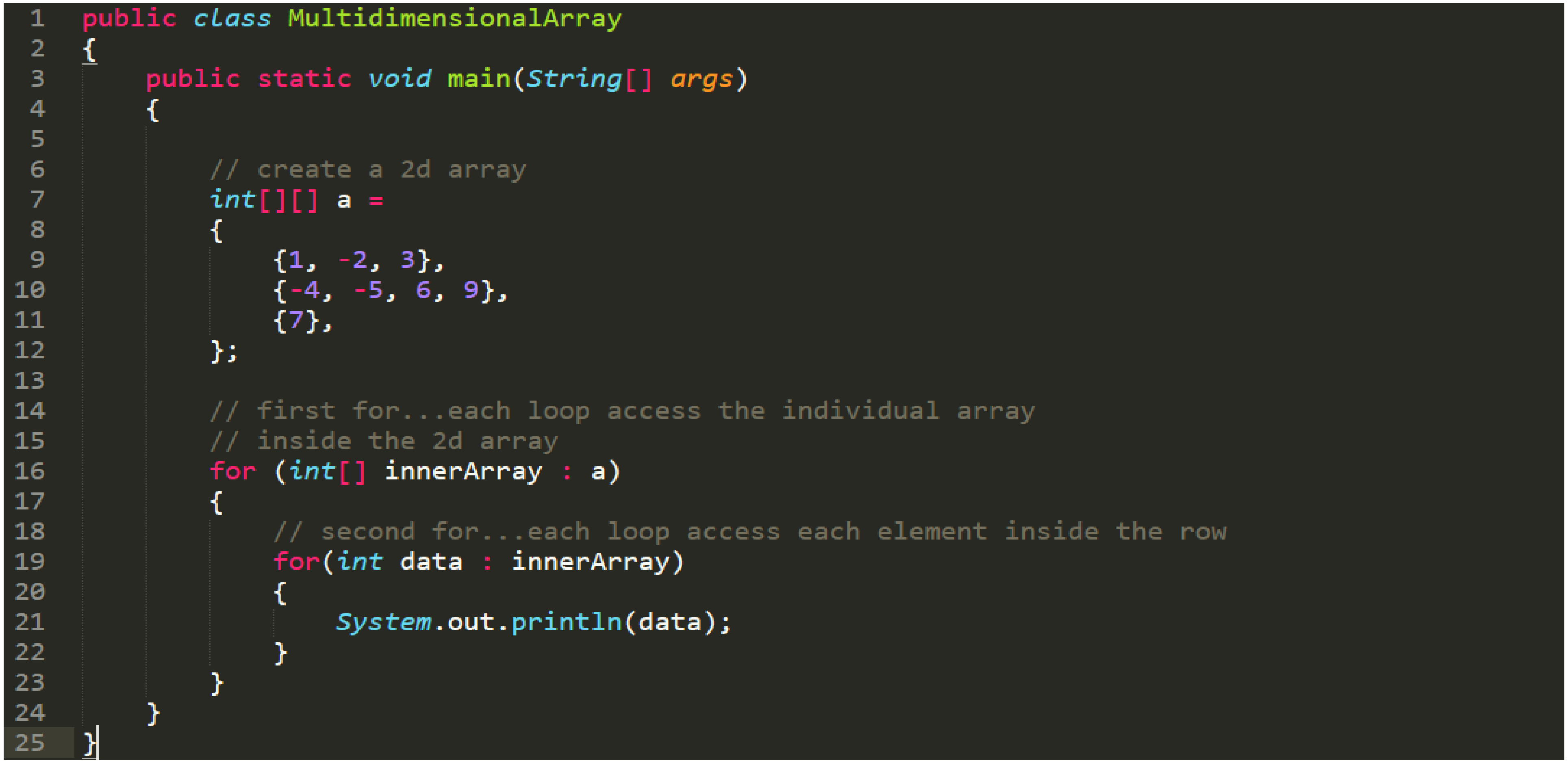


```java
public class MultidimensionalArray {
    public static void main(String[] args)
    {

        int[][] a =
        {
            {1, -2, 3},
            {-4, -5, 6, 9},
            {7},
        };

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

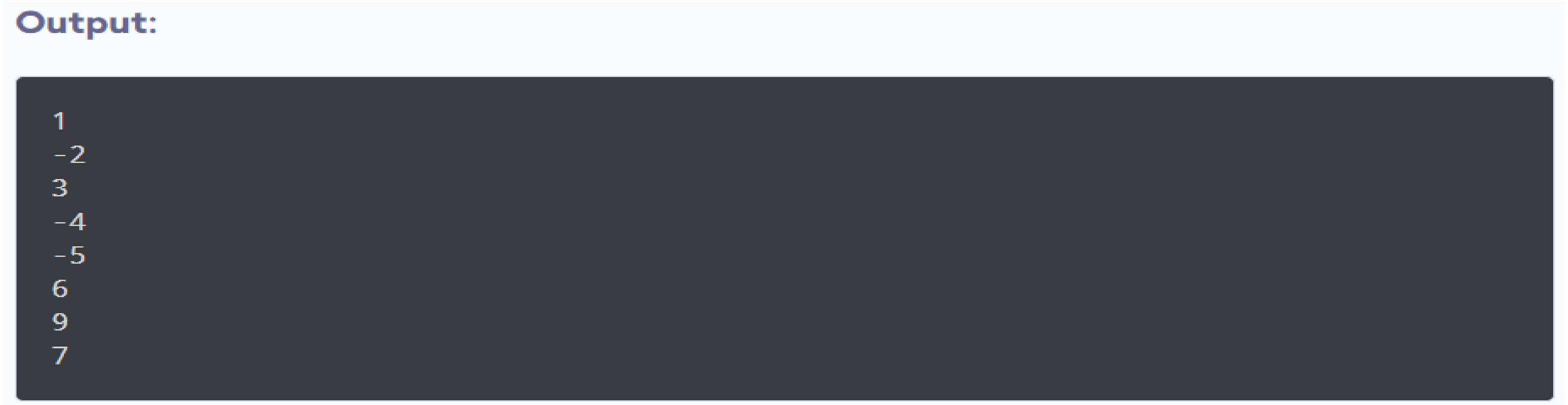


Output:

```
1
-2
3
-4
-5
6
9
7
```

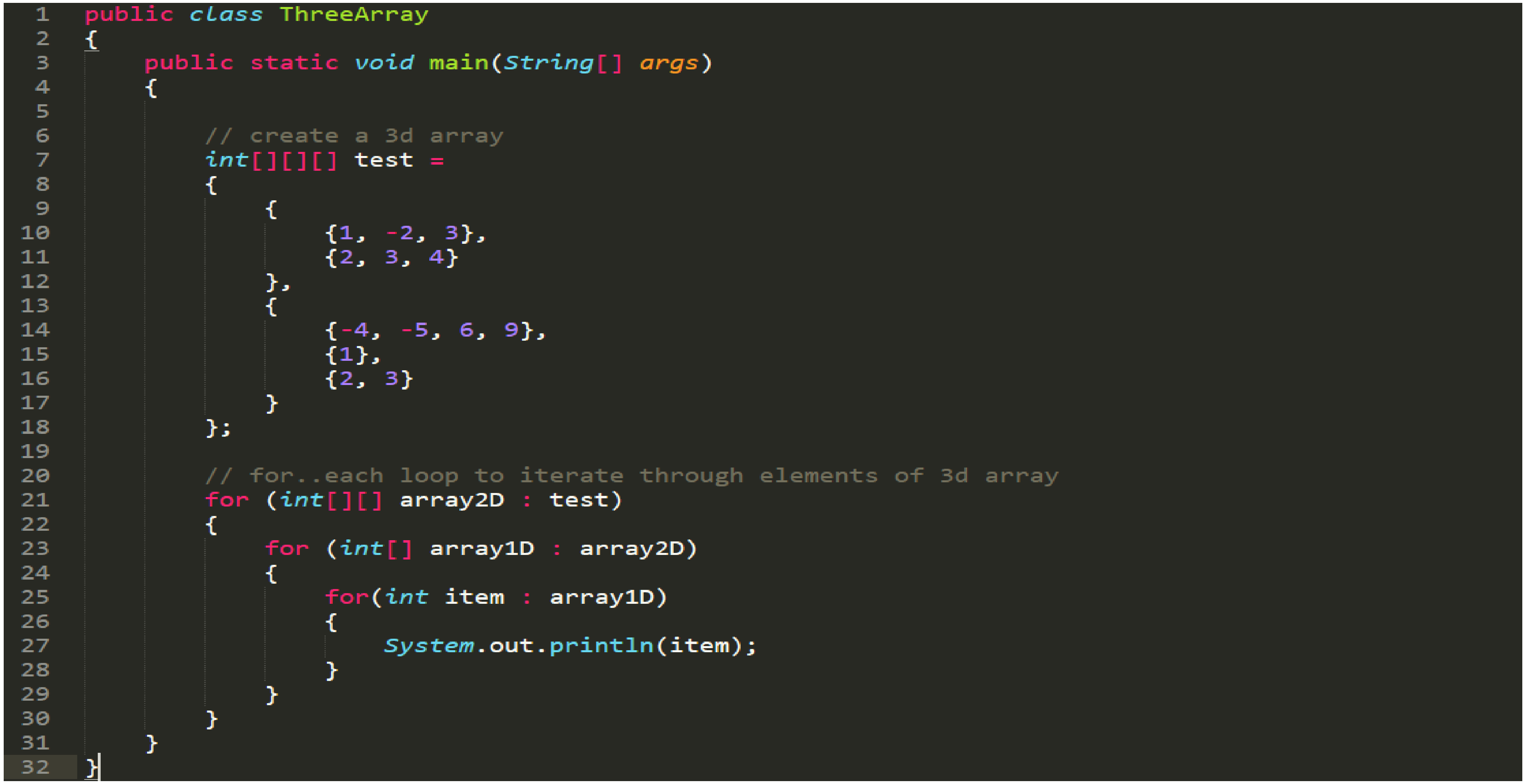


```java
public class MultidimensionalArray
{
    public static void main(String[] args)
    {

        // create a 2d array
        int[][] a =
        {
            {1, -2, 3},
            {-4, -5, 6, 9},
            {7},
        };

        // first for...each loop access the individual array
        // inside the 2d array
        for (int[] innerArray : a)
        {
            // second for...each loop access each element inside the row
            for(int data : innerArray)
            {
                System.out.println(data);
            }
        }
    }
}
```

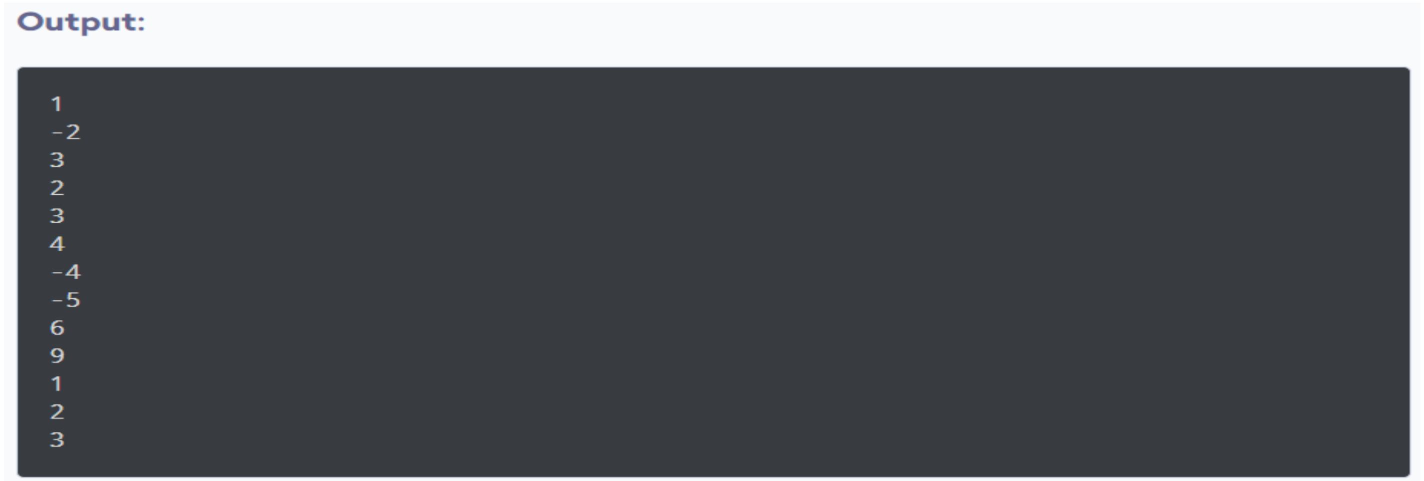


Output:

```
1
-2
3
-4
-5
6
9
7
```



```java
public class ThreeArray
{
    public static void main(String[] args)
    {

        // create a 3d array
        int[][][] test =
        {
            {
                {1, -2, 3},
                {2, 3, 4}
            },
            {
                {-4, -5, 6, 9},
                {1},
                {2, 3}
            }
        };

        // for..each loop to iterate through elements of 3d array
        for (int[][] array2D : test)
        {
            for (int[] array1D : array2D)
            {
                for(int item : array1D)
                {
                    System.out.println(item);
                }
            }
        }
    }
}
```

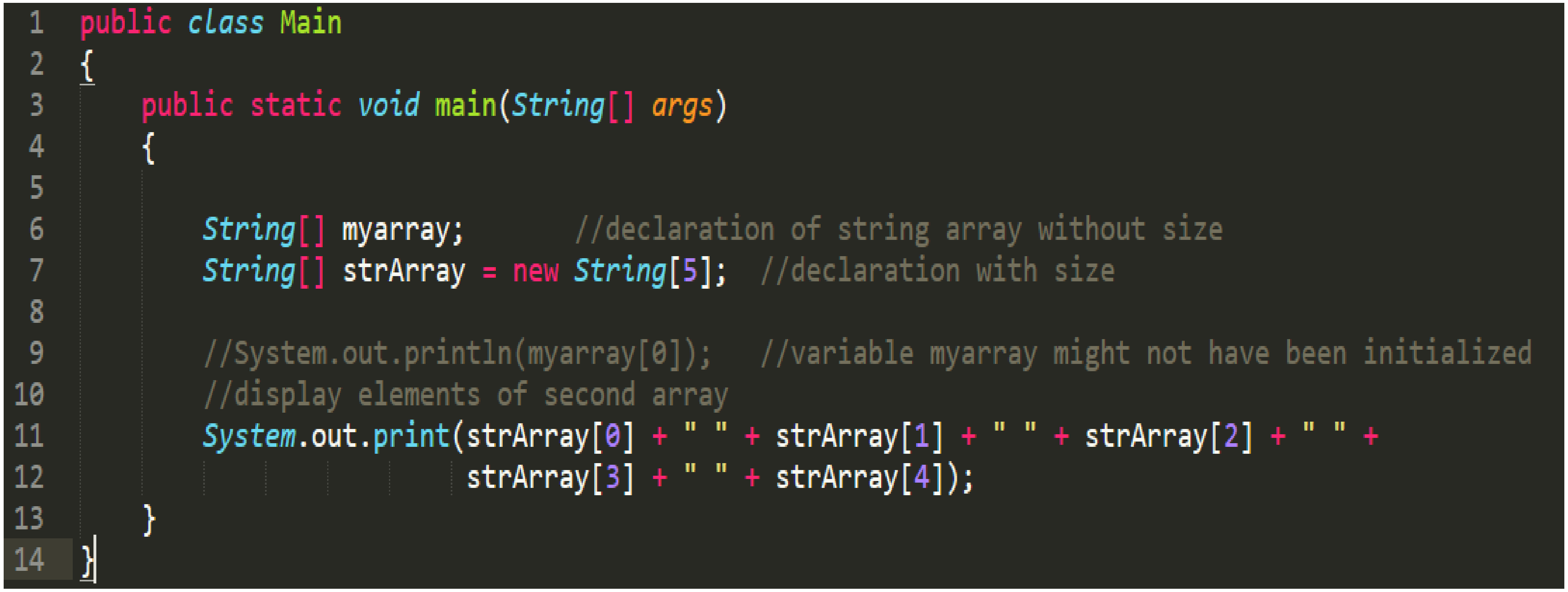


Output:

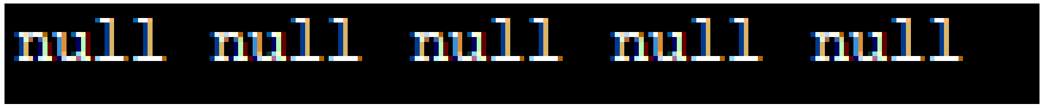
```
1
-2
3
2
3
4
-4
-5
6
9
1
2
3
```

Examples: String array

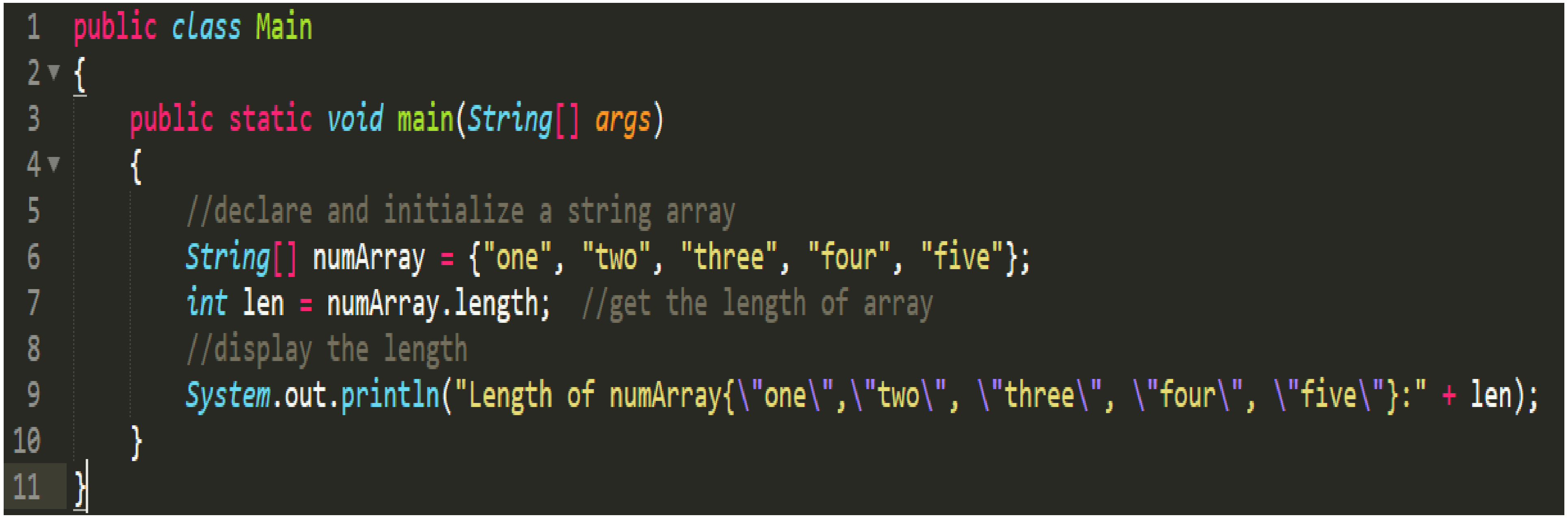
- String Array is an array holding a fixed number of strings or string values
  - One structure commonly used in Java
  - Even the argument of the ‘main’ function in Java is a String Array
- String array is an array of objects
  - String is an object



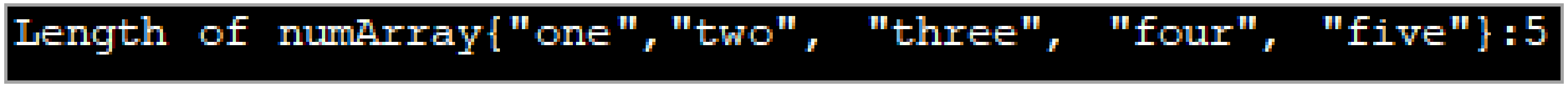
```java
public class Main
{
    public static void main(String[] args)
    {

        String[] myarray;       //declaration of string array without size
        String[] strArray = new String[5];  //declaration with size

        //System.out.println(myarray[0]);   //variable myarray might not have been initialized
        //display elements of second array
        System.out.print(strArray[0] + " " + strArray[1] + " " + strArray[2] + " " +
                         strArray[3] + " " + strArray[4]);
    }
}
```



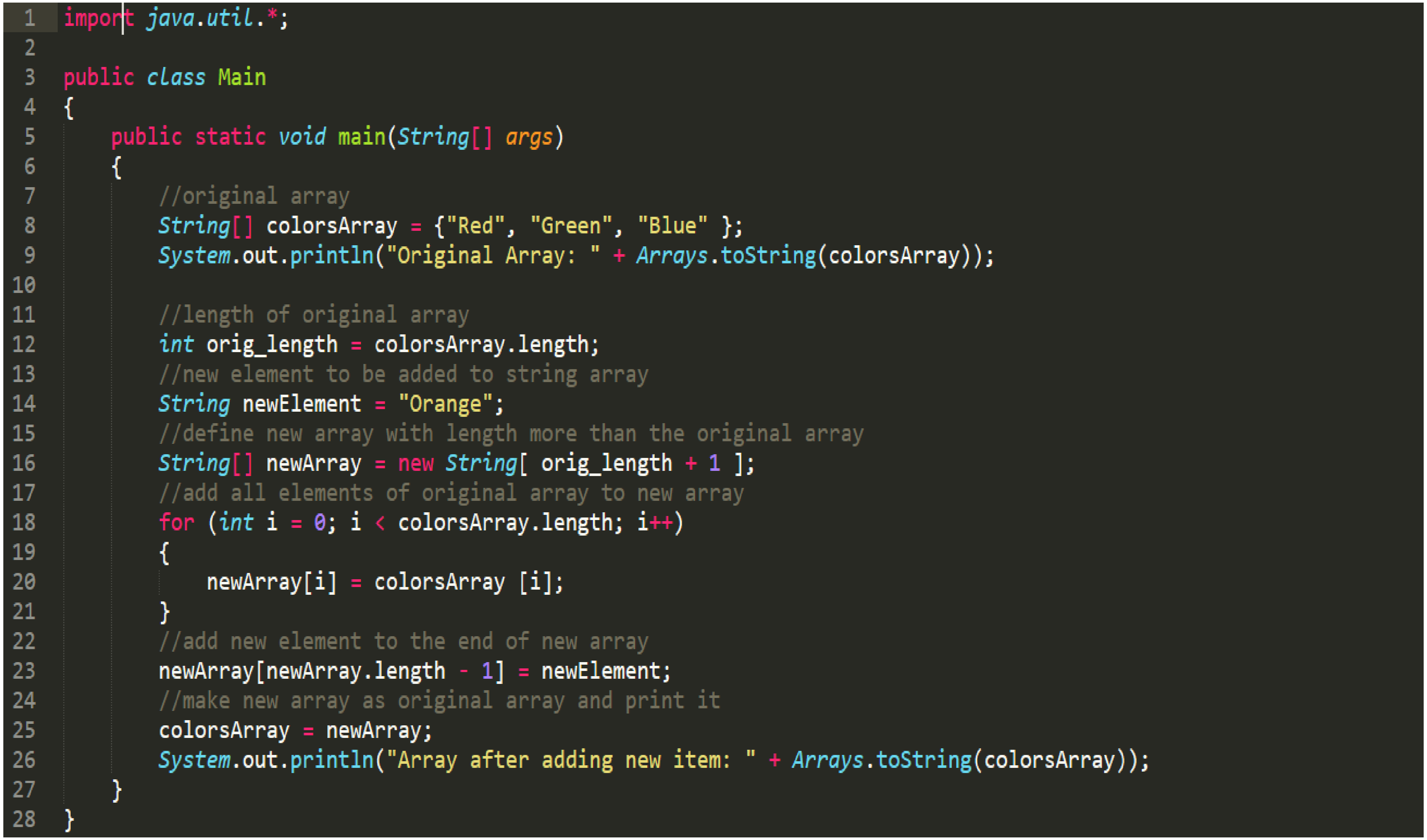
```
null null null null null
```



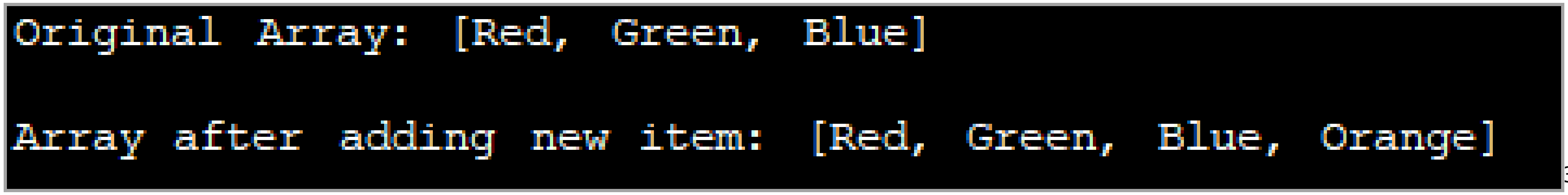
```java
public class Main
{
    public static void main(String[] args)
    {
        //declare and initialize a string array
        String[] numArray = {"one", "two", "three", "four", "five"};
        int len = numArray.length;  //get the length of array
        //display the length
        System.out.println("Length of numArray{\"one\",\"two\", \"three\", \"four\", \"five\"}:" + len);
    }
}
```



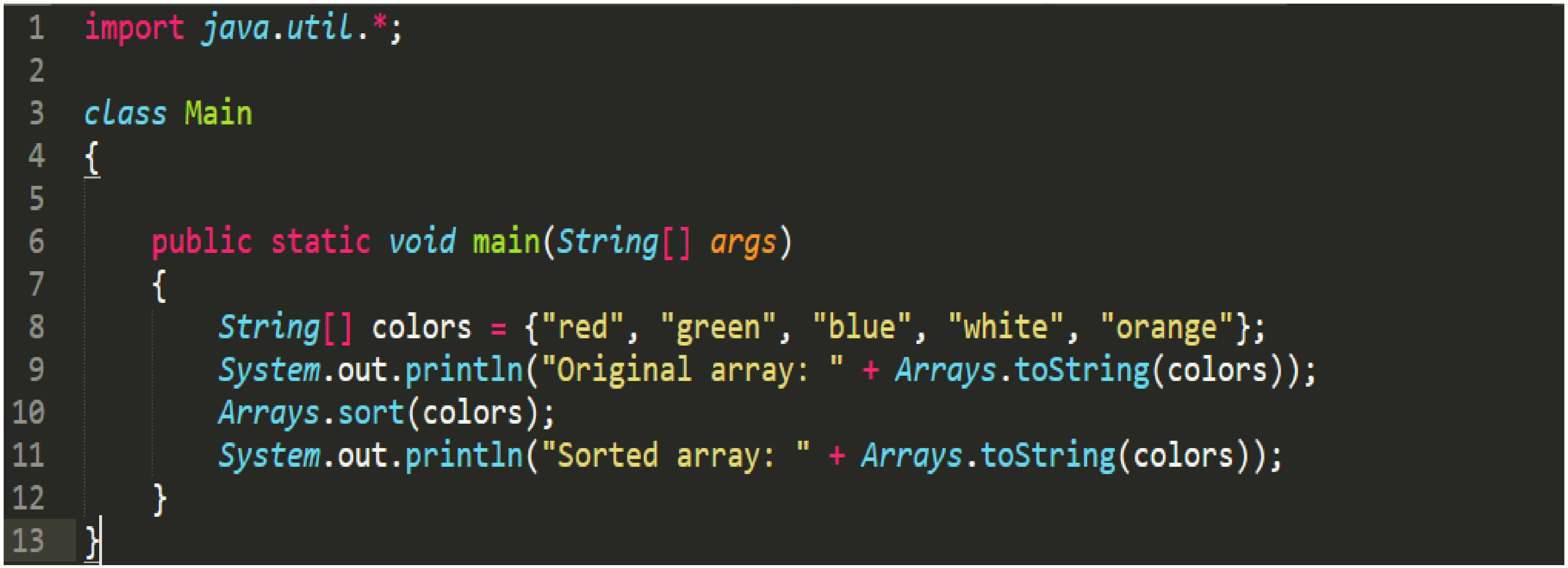
```
Length of numArray{"one","two", "three", "four", "five"}:5
```



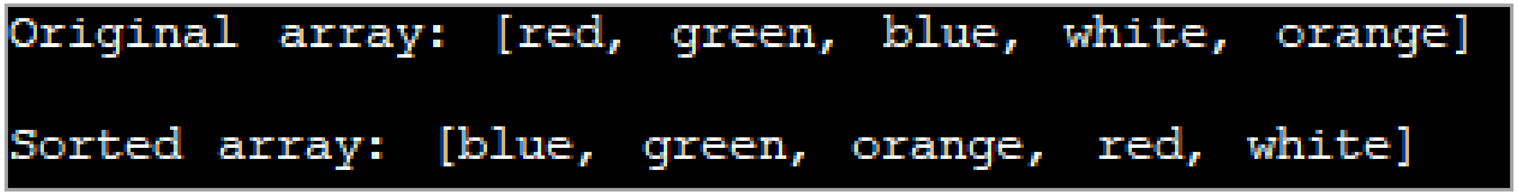
```java
import java.util.*;

public class Main
{
    public static void main(String[] args)
    {
        //original array
        String[] colorsArray = {"Red", "Green", "Blue" };
        System.out.println("Original Array: " + Arrays.toString(colorsArray));

        //length of original array
        int orig_length = colorsArray.length;
        //new element to be added to string array
        String newElement = "Orange";
        //define new array with length more than the original array
        String[] newArray = new String[ orig_length + 1 ];
        //add all elements of original array to new array
        for (int i = 0; i < colorsArray.length; i++)
        {
            newArray[i] = colorsArray [i];
        }
        //add new element to the end of new array
        newArray[newArray.length - 1] = newElement;
        //make new array as original array and print it
        colorsArray = newArray;
        System.out.println("Array after adding new item: " + Arrays.toString(colorsArray));
    }
}
```



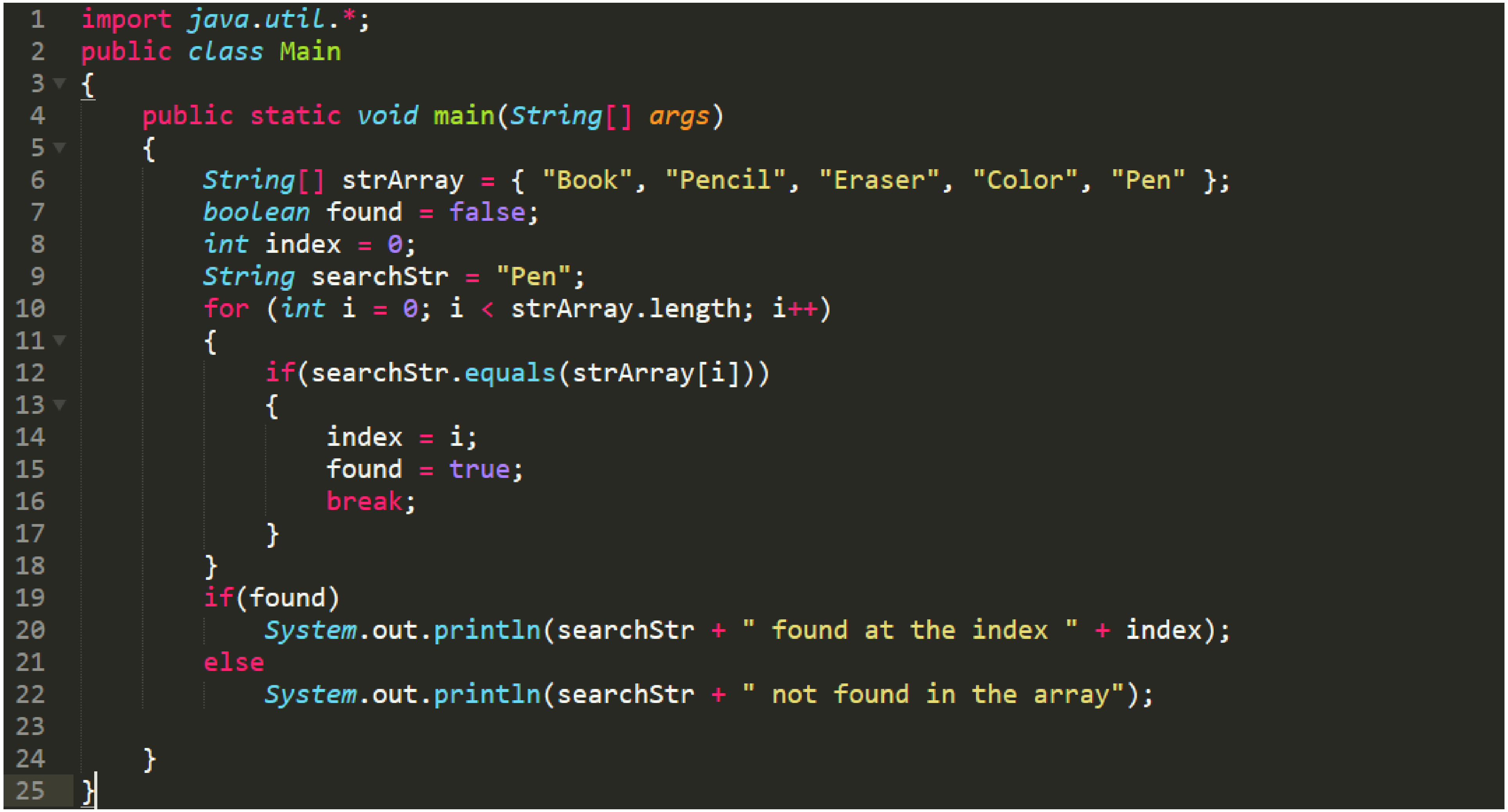
```
Original Array: [Red, Green, Blue]

Array after adding new item: [Red, Green, Blue, Orange]
```



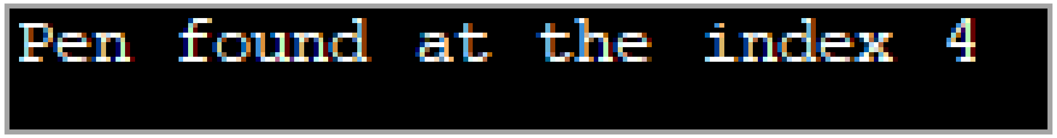
```java
import java.util.*;

class Main
{

    public static void main(String[] args)
    {
        String[] colors = {"red", "green", "blue", "white", "orange"};
        System.out.println("Original array: " + Arrays.toString(colors));
        Arrays.sort(colors);
        System.out.println("Sorted array: " + Arrays.toString(colors));
    }
}
```



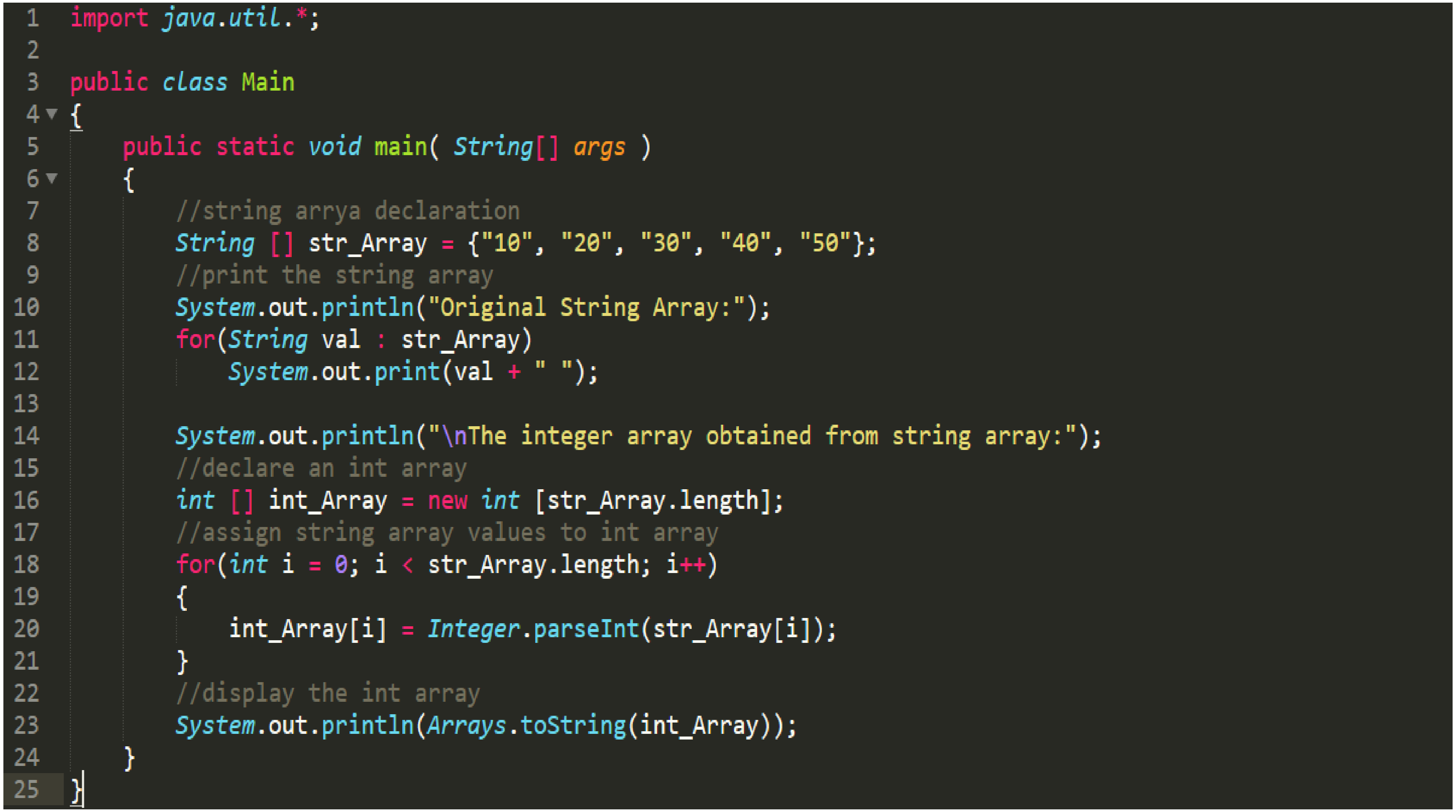
```
Original array: [red, green, blue, white, orange]

Sorted array: [blue, green, orange, red, white]
```



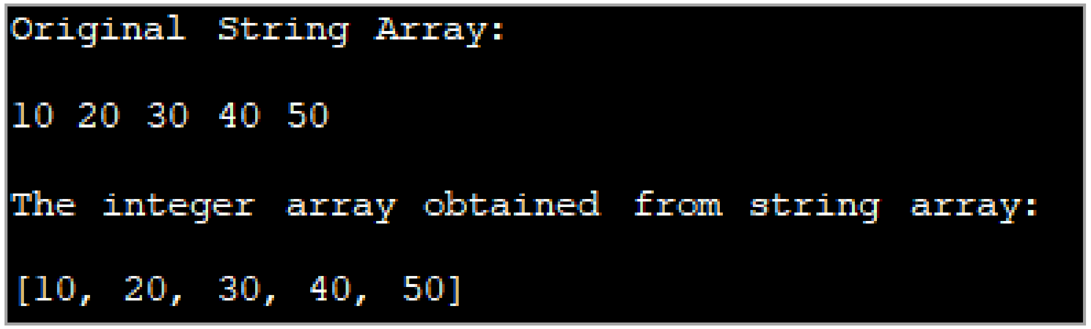
```java
import java.util.*;
public class Main
{
    public static void main(String[] args)
    {
        String[] strArray = { "Book", "Pencil", "Eraser", "Color", "Pen" };
        boolean found = false;
        int index = 0;
        String searchStr = "Pen";
        for (int i = 0; i < strArray.length; i++)
        {
            if(searchStr.equals(strArray[i]))
            {
                index = i;
                found = true;
                break;
            }
        }
        if(found)
            System.out.println(searchStr + " found at the index " + index);
        else
            System.out.println(searchStr + " not found in the array");

    }
}
```



```
Pen found at the index 4
```



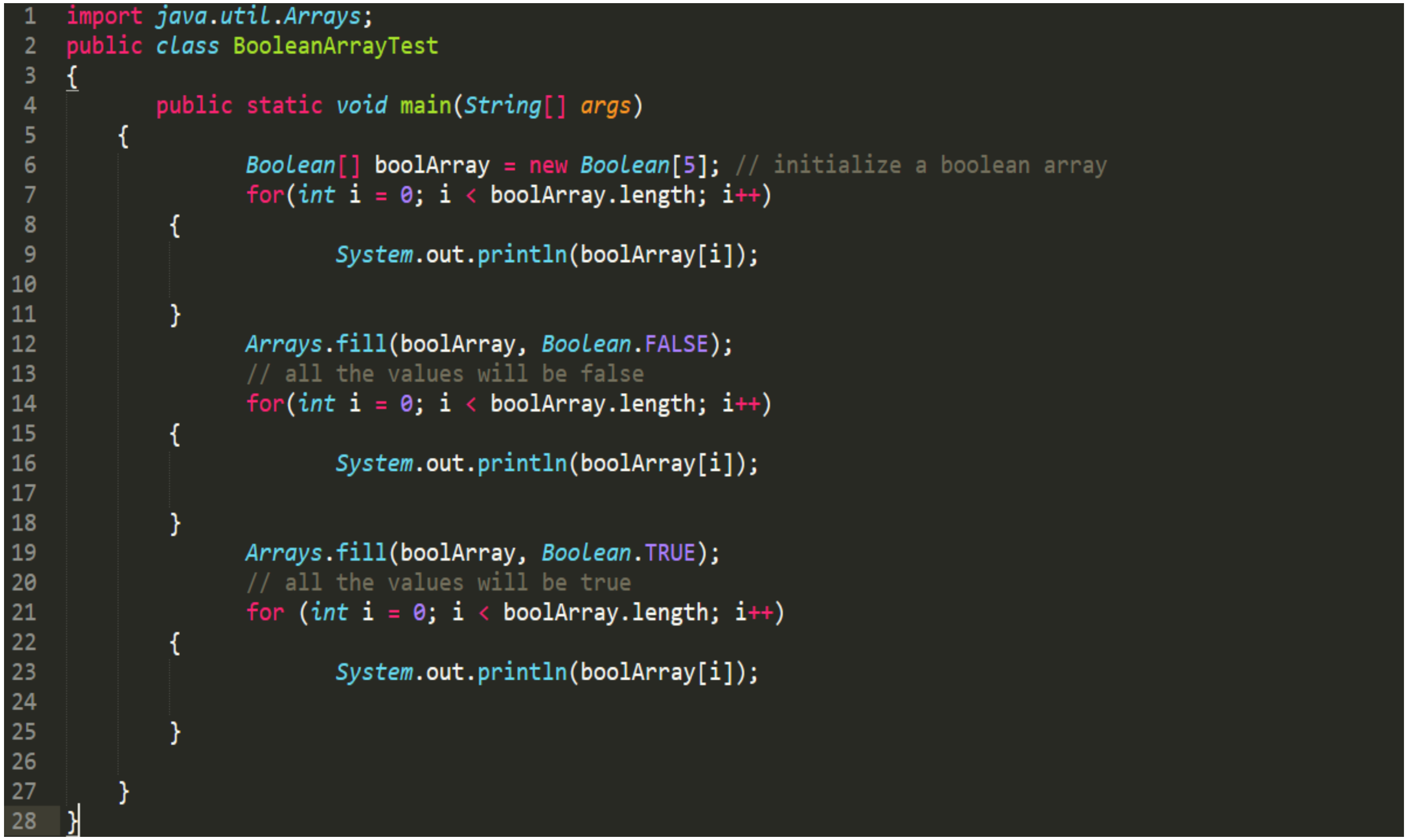
```java
import java.util.*;

public class Main
{
    public static void main( String[] args )
    {
        //string arrya declaration
        String [] str_Array = {"10", "20", "30", "40", "50"};
        //print the string array
        System.out.println("Original String Array:");
        for(String val : str_Array)
            System.out.print(val + " ");

        System.out.println("\nThe integer array obtained from string array:");
        //declare an int array
        int [] int_Array = new int [str_Array.length];
        //assign string array values to int array
        for(int i = 0; i < str_Array.length; i++)
        {
            int_Array[i] = Integer.parseInt(str_Array[i]);
        }
        //display the int array
        System.out.println(Arrays.toString(int_Array));
    }
}
```



```
Original String Array:

10 20 30 40 50

The integer array obtained from string array:

[10, 20, 30, 40, 50]
```

Examples: Boolean array

- Each element of array is a Boolean value (true, false)



```
import java.util.Arrays;
public class BooleanArrayTest
{
        public static void main(String[] args)
    {
                Boolean[] boolArray = new Boolean[5]; // initialize a boolean array
                for(int i = 0; i < boolArray.length; i++)
        {
                        System.out.println(boolArray[i]);

        }
                Arrays.fill(boolArray, Boolean.FALSE);
                // all the values will be false
                for(int i = 0; i < boolArray.length; i++)
        {
                        System.out.println(boolArray[i]);

        }
                Arrays.fill(boolArray, Boolean.TRUE);
                // all the values will be true
                for (int i = 0; i < boolArray.length; i++)
        {
                        System.out.println(boolArray[i]);

        }

    }
}
```

What is the output?

Recommended reading

- Reading this week
  - Chapter 1, textbook
- Next lecture
  - Insertion/Merge sort: chapter 3, textbook