Chapter 4: Arrays

Yepang LIU (刘烨庞)

liuyp1@sustech.edu.cn

Why using Array?

- Suppose that you need to read 100 numbers and find out how many numbers are above the average.
- Your program should compare each number with the average to determine whether it is above the average.

Declaring individual variables for each number, such as `number0`, `number1`, . . . , and `number99` would be impractical

Why using Array?

- Java and most other high-level languages provide a data structure, the `array`, which stores a fixed-size sequential collection of elements of the same type.
- In the example, you can store all 100 numbers into an array and access them through a single array variable.

Objectives

- Declare and initialize arrays
- Access individual elements of arrays
- Use the enhanced `foreach` statement to process arrays
- Copying arrays
- 2D arrays & multidimensional arrays

Arrays

- An **array** (a widely-used data structure) is **a group of elements** containing values of **the same type**.
- Arrays are objects, so they're considered **reference types** (aka non-primitive types) (we will talk about this more later)

Declaring Arrays

- To use an array in a program, you must declare a variable to reference the array and specify the array's element type.

```
ElementType[] variableName;
```

- The ElementType can be any data type (primitive or reference type), and all elements in the array will have the same data type.

```
int[] intArray;

double[] doubleArray;

String[] stringArray;
```

Creating Arrays

- The declaration of an array variable does not allocate any space in memory for the array elements, and we cannot use the array before creating (initializing) it.

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

- Like other objects (recall the usage of `Scanner`), arrays are created with the keyword `new`.
- 12 means the size of the array. When space for an array is allocated, the array size must be given.
- The size of an array cannot be changed after the array is created.

Creating Arrays

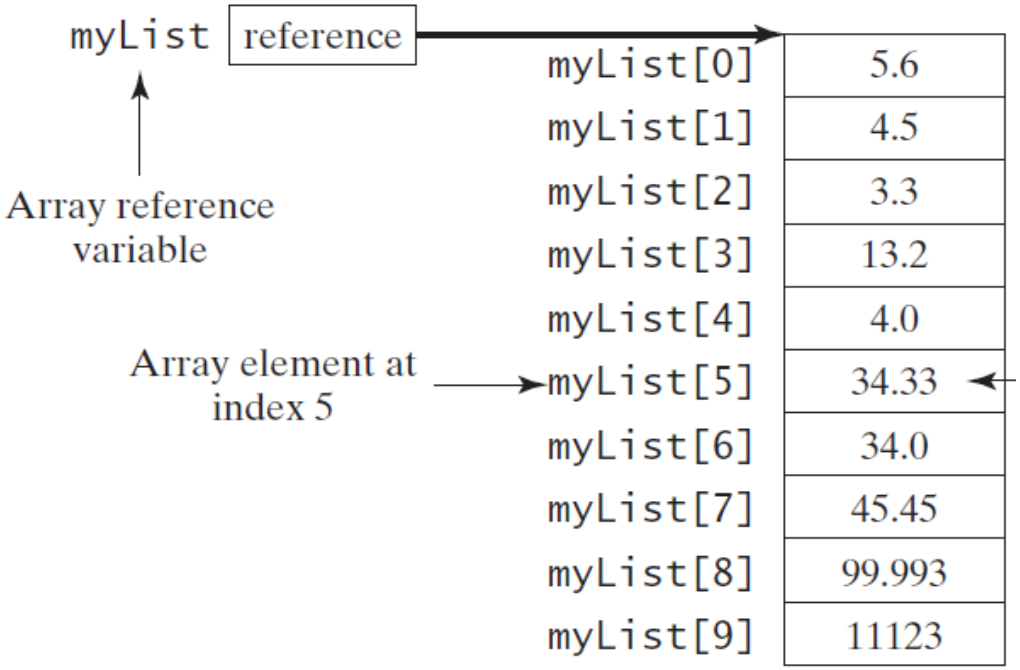
- The declaration of an array variable does not allocate any space in memory for the array elements, and we cannot use the array before creating (initializing) it.

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

- Variable `c` refers to an array of size 12 with elements of `int` type
- When an array is created, its elements are assigned the default value of `0` for the numeric primitive data types, `\u0000` for char types, and `false` for boolean types.

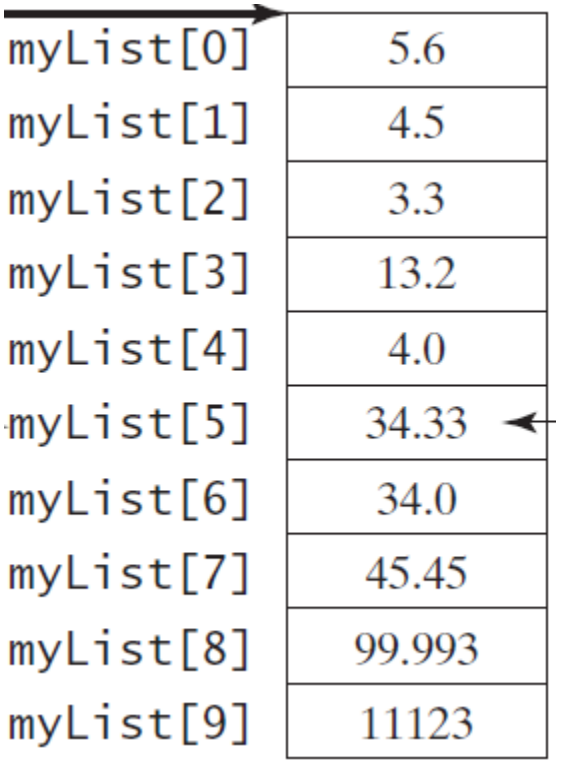
Accessing Array Elements

```
double[] myList = new double[10];
myList[0] = 5.6;
myList[1] = 4.5;
myList[2] = 3.3;
myList[3] = 13.2;
myList[4] = 4.0;
myList[5] = 34.33;
myList[6] = 34.0;
myList[7] = 45.45;
myList[8] = 99.993;
myList[9] = 11123;
```



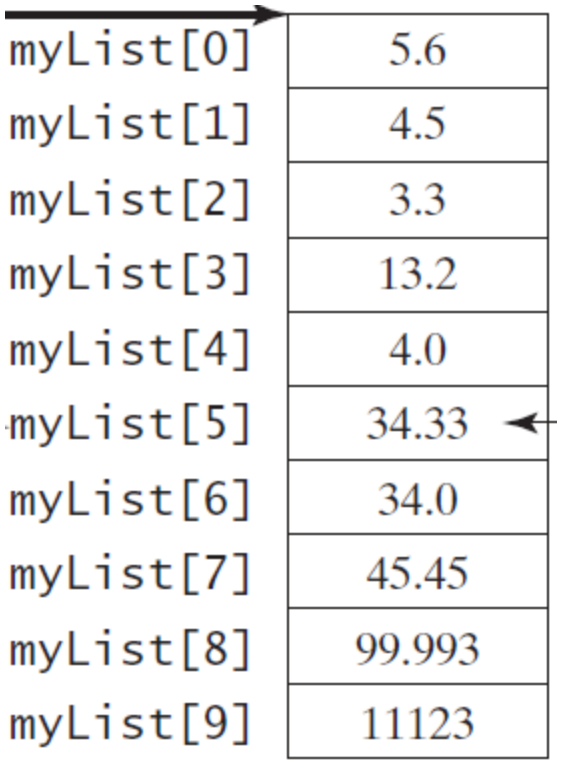
Size can be obtained using `arrayRefVar.length`. For example, `myList.length` is 10 (here, `.` is a member selection operator).

Accessing Array Elements



- The array elements are accessed through the index.
- The first element in every array has index 0.
- The highest index in an array is the number of elements – 1, i.e., `myList.length-1`

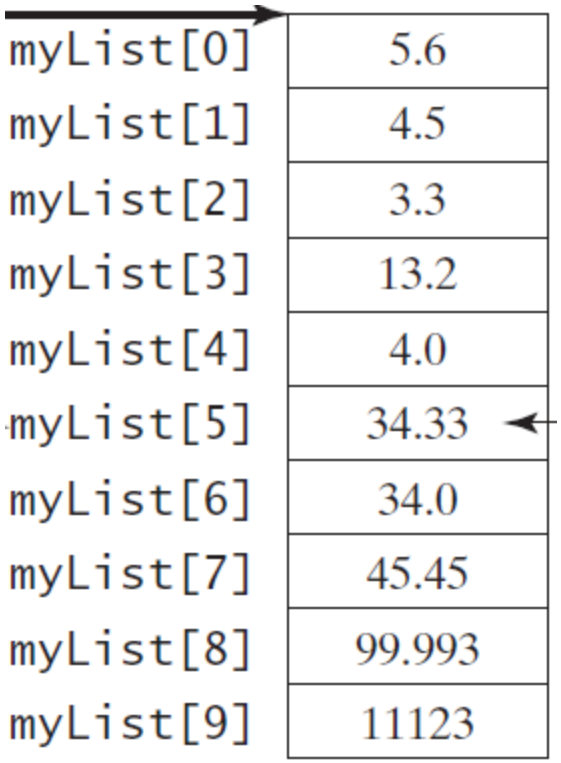
Accessing Array Elements



`myList[5]` refers to the 6th element

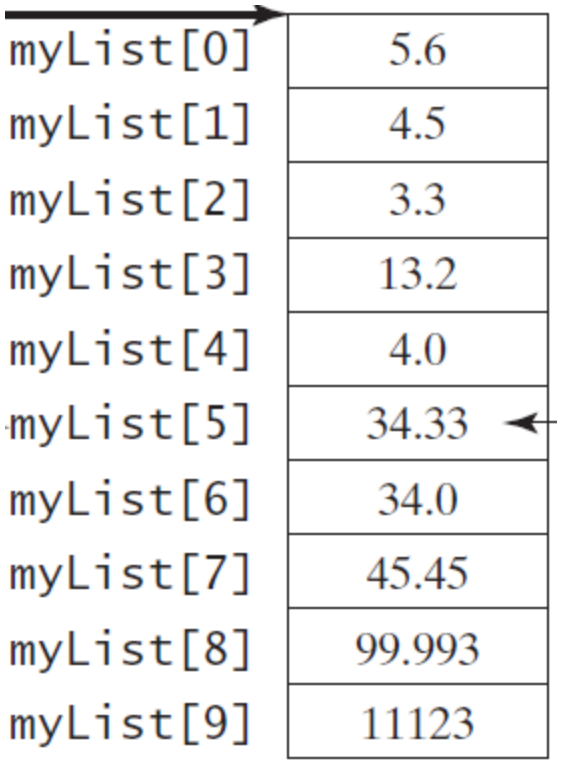
- myList is the reference to the array (or name of the array for simplicity)
- 5 is the position number of the element (index or subscript)

Accessing Array Elements



- A program can use an expression as an index (`c[1+a]`)
- An index must be a nonnegative integer (c[-2] causes error).
- If an index<0 or index>array.length-1, you'll get an `ArrayIndexOutOfBounds` Exception

Accessing Array Elements



- Array-access expressions can be used to get element value (read) or on the left-hand side of an assignment to place a new value into an array element (write)

myList[1] = 2.2; → write

System.*out*.println(myList[1]); → read

Print an array

```
int[] array = new int[10];
System.out.println(array);
```

[I@776ec8df

Array is a reference type. We cannot directly print a variable of the array type as we do for primitive types*

*A char array can be directly printed

Print an array

The `int` elements by default get the value of 0

```
int[] array = new int[10];

System.out.printf("%s%8s\n", "Index", "Value");

// Using loop to output each array element's value
for(int counter = 0; counter < array.length; counter++) {
    System.out.printf("%3d%8d\n", counter, array[counter]);
}
```

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

Make sure the index is within **[0, array.length – 1]**

Otherwise: `java.lang.ArrayIndexOutOfBoundsException` 

Array Initialization

- You can create an array and initialize its elements with an array initializer—a comma-separated list of expressions enclosed in braces.

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

- Compiler counts the # of values in the list to determine the size of the array, then sets up the appropriate `new` operation "behind the scenes".
- Element `n[0]` is initialized to `10`, `n[1]` is initialized to `20`, and so on.

Array Initialization

- You can create an array and initialize its elements with an array initializer—a comma-separated list of expressions enclosed in braces.

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

- Shortcut: initialize the array without using the new keyword
- This shortcut is allowed only at the time of array declaration

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

Array initializer is not allowed here

Add 'new int[]' Alt+Shift+Enter

Array Initialization

How to initialize the array to output these numbers?

```
int[] array = new int[10];




System.out.printf("%s%8s\n", "Index", "Value");
// output each array element's value
for(int counter = 0; counter < array.length; counter++) {
  System.out.printf("%3d%8d\n", counter, array[counter]);
}
```

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

Array Initialization

```
int[] array = {2,4,6,8,10,12,14,16,18,20};
```

```
System.out.printf("%s%8s\n", "Index", "Value");
// output each array element's value
for(int counter = 0; counter < array.length; counter++) {
  System.out.printf("%3d%8d\n", counter, array[counter]);
}
```

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


Array Initialization

```
int[] array = new int[10];
//calculate value for each array element
for(int counter = 0; counter < array.length; counter++) {
  array[counter] = 2 + 2 * counter;
}
System.out.printf("%s%8s\n", "Index", "Value");
// output each array element's value
for(int counter = 0; counter < array.length; counter++) {
  System.out.printf("%3d%8d\n", counter, array[counter]);
}
```

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


A Dice-Rolling Program

- Suppose we want to roll a dice 6000 times and count the frequency of each side
- We can use separate counters as below
  - `int faceOneFreq, faceTwoFreq, …`
- Now we have learned arrays. Is there a better design?

```java
import java.util.Random;
public class DiceRolling {
  public static void main(String[] args) {
    Random generator = new Random();
    int[] frequency = new int[6];
    // roll 6000 times; use dice value as frequency index
    for(int roll = 1; roll <= 6000; roll++) {
      int face = generator.nextInt(6);
      frequency[face]++;
    }
    System.out.printf("%s%10s\n", "Face", "Frequency");
    // output the frequency of each face
    for(int face = 0; face < frequency.length; face++) {
      System.out.printf("%4d%10d\n", face+1, frequency[face]);
    }
  }
}
```

Use an array to track frequency

`nextInt(6)` generates [0, 5]

Execution Result

```
Face Frequency
   1      1016
   2       991
   3       981
   4      1011
   5       988
   6      1013
```

Objectives

- Declare and initialize arrays
- Access individual elements of arrays
- Use the enhanced `foreach` statement to process arrays
- Copying arrays
- 2D arrays & multidimensional arrays

foreach Statement

- Java supports a convenient for loop, known as a `foreach` loop, which enables you to traverse the array sequentially without using an index variable.

```
for (double e: myList) {
  System.out.println(e);
}
```

Avoid the possibility of "stepping outside" the array.

foreach Statement

- *arrayName* is the array through which to iterate.
- *identifier* can be used to refer to each array element.
- *ElementType* must be consistent with the type of the elements in the array.

```
for ( ElementType identifier : arrayName ) {
    // do something with the identifier
}
```

foreach Statement

- Simple syntax compared to the normal `for` statement

```
for ( int num : numbers ) {
   // statements using num
}
```

Semantically equivalent

```
for ( int i = 0; i < numbers.length; i++ ) {
   int num = numbers[i];
   // statements using num
}
```

foreach Statement

- Often used to replace counter-controlled `for` statement when the code requires only **read access** to element values.

```
for ( int i = 0; i < numbers.length; i++ ) {
   total += numbers[i];
}
```

```
for ( int num : numbers ) {
   total += num;
}
```

Simple and elegant ☺

foreach Statement

- Cannot be used to modify element values

```
for ( int num : numbers ) {
   num = 0;
}
```

Can this change the array element values?

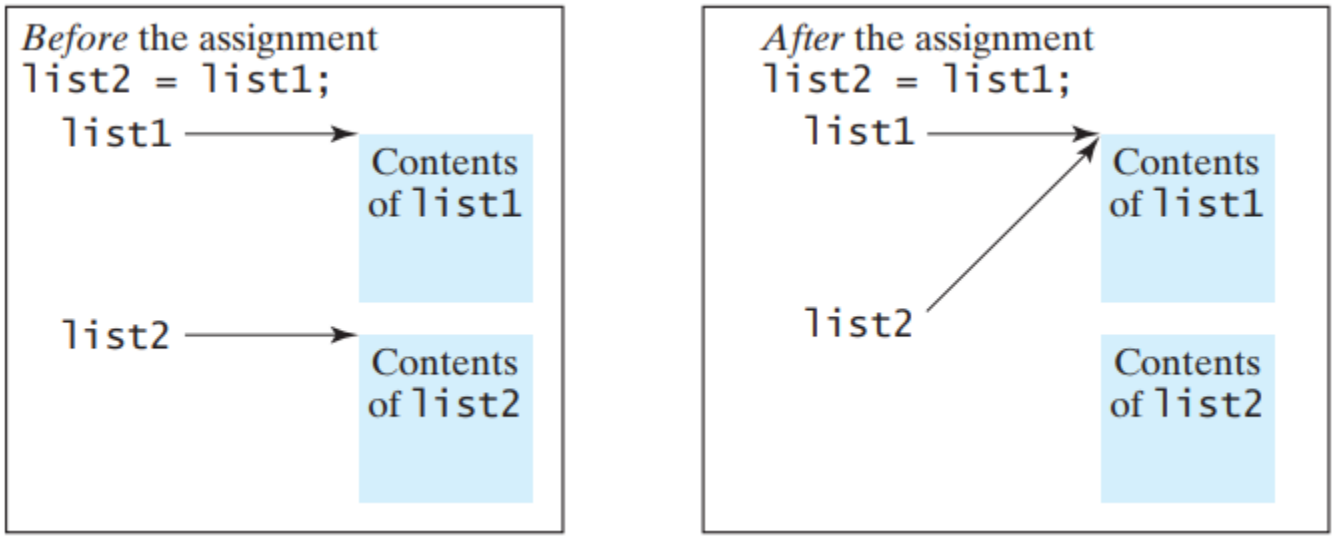
No! Only change the value of num

```
for ( int i = 0; i < numbers.length; i++ ) {
   int num = numbers[i];
   num = 0;
}
```

Local variable num stores a copy of the array element value

Copying Arrays

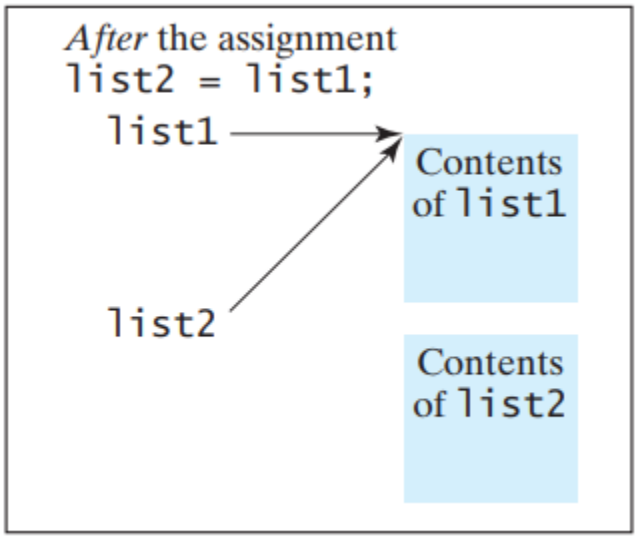
- The assignment statement does not copy the contents of the array referenced by `list1` to `list2`, but instead merely copies the reference value from `list1` to `list2`.
- After this statement, `list1` and `list2` reference the same array



Copying Arrays

- The assignment statement does not copy the contents of the array referenced by `list1` to `list2`, but instead merely copies the reference value from `list1` to `list2`.
- After this statement, `list1` and `list2` reference the same array

```
int[] list1 = {1,2,3,4,5};
int[] list2 = {6,7,8,9};

list2 = list1;
System.out.println(Arrays.toString(list2));
// [1, 2, 3, 4, 5]

list1[3] = 100;
System.out.println(Arrays.toString(list2));
// [1, 2, 3, 100, 5]
```



Copying Arrays

- You can write a loop to copy every element from the source array to the corresponding element in the target array.

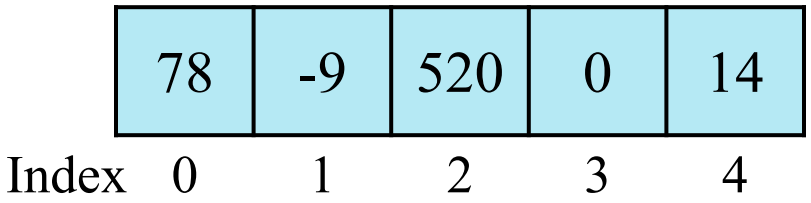
```
int[] sourceArray = {2, 3, 1, 5, 10};
int[] targetArray = new int[sourceArray.length];
for (int i = 0; i < sourceArray.length; i++) {
  targetArray[i] = sourceArray[i];
}
```

Objectives

- Declare and initialize arrays
- Access individual elements of arrays
- Use the enhanced `foreach` statement to process arrays
- Copying arrays
- 2D arrays & multidimensional arrays

One-Dimensional Arrays

- Arrays that we have considered up to now are one-dimensional arrays: a single line of elements.



Example: an array of five random numbers

Two-Dimensional Arrays

- Data in real life often come in the form of a table

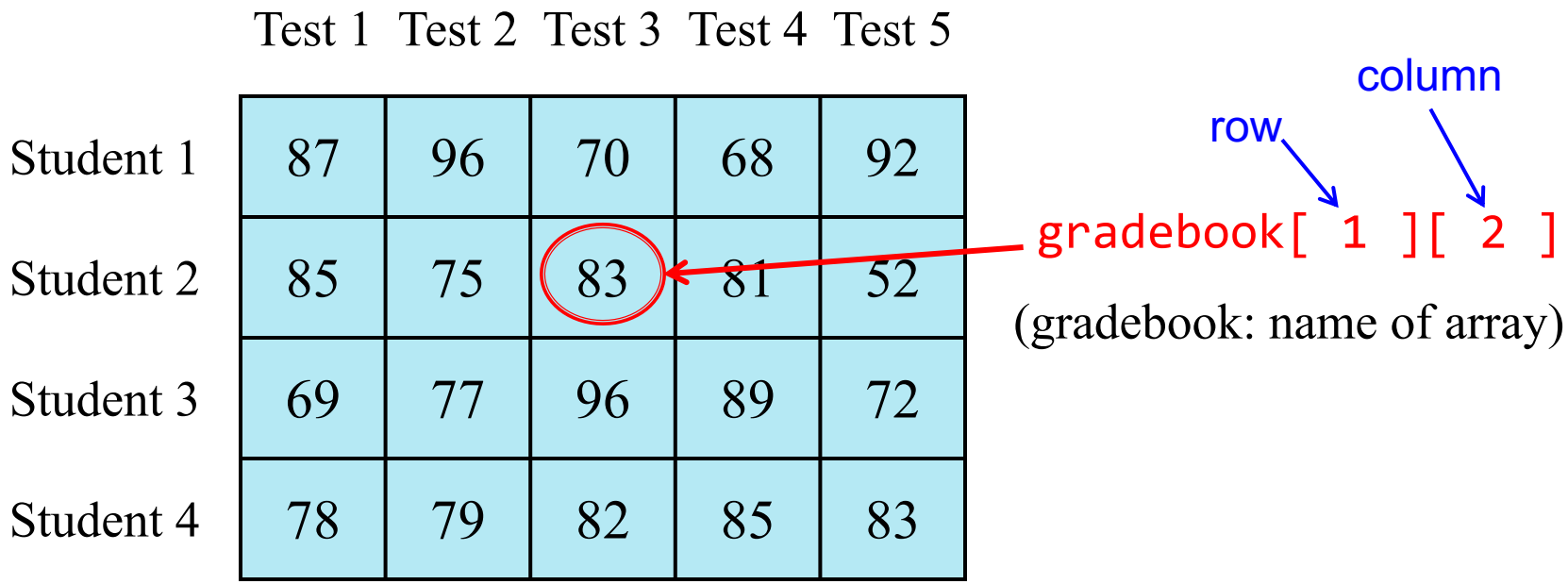
	Test 1	Test 2	Test 3	Test 4	Test 5
Student 1	87	96	70	68	92
Student 2	85	75	83	81	52
Student 3	69	77	96	89	72
Student 4	78	79	82	85	83

Example:
a gradebook

The table can be represented using a two-dimensional array in Java

Two-Dimensional (2D) Arrays

- 2D arrays are indexed by two subscripts: one for the row number, the other for the column number. Subscripts start with 0.



2D Array Basics (Similar to 1D Array)

- Similar to 1D array, each element in a 2D array should be of the same type: either primitive type or reference type
- Array access expression (subscripted variables) can be used just like a normal variable: `gradebook[1][2] = 77;`
- Array indices (subscripts) must be of type `int`, can be a literal, a variable, or an expression: `gradebook[1][j], gradebook[i+1][j+1]`
- If an array index does not exist, JVM will throw an exception `ArrayIndexOutOfBoundException`

Declaring and Creating 2D Arrays

- Declares a variable that references a 2D array of `int`

```
int[][] gradebook;
```

- Creates a 2D array **(50-by-6 array)** with **50 rows** (for 50 students) and **6 columns** (for 6 tests) and assign the array reference to the variable `gradebook`

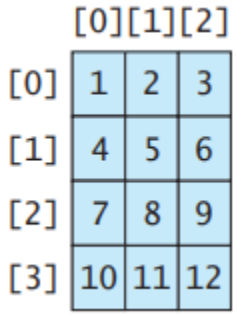
```
gradebook = new int[50][6];
```

Shortcut: `int[][] gradebook = new int[50][6];`

Array Initialization

We can initialize a 2D array by assigning to each element, or with nested array initializers

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




```
int[][] array = {
  {1, 2, 3},
  {4, 5, 6},
  {7, 8, 9},
  {10, 11, 12}
};
```

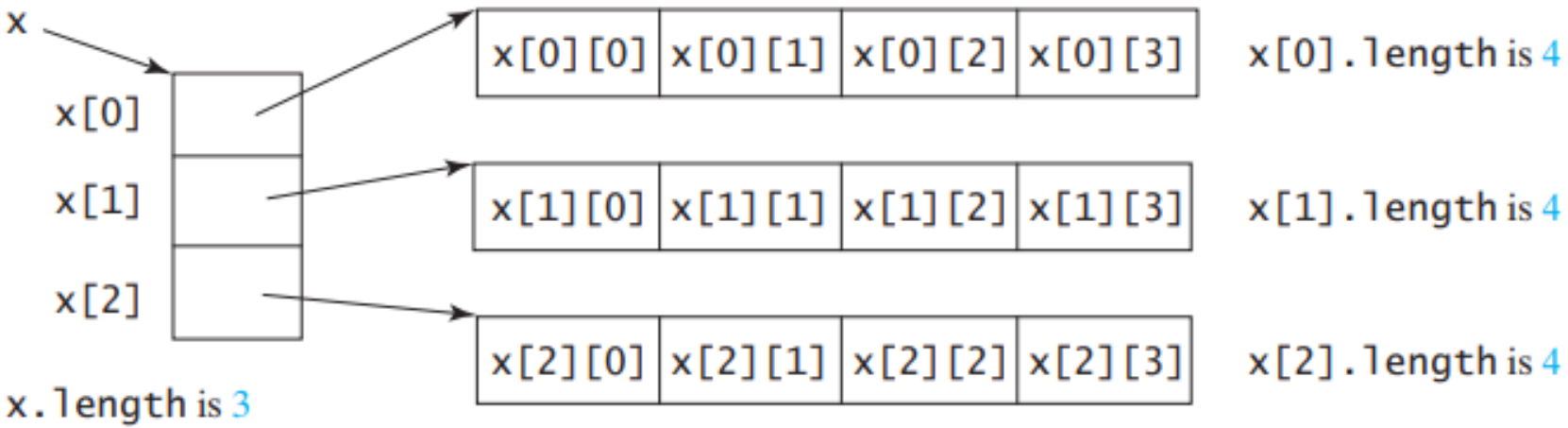
Equivalent

```
int[][] array = new int[4][3];
array[0][0] = 1; array[0][1] = 2; array[0][2] = 3;
array[1][0] = 4; array[1][1] = 5; array[1][2] = 6;
array[2][0] = 7; array[2][1] = 8; array[2][2] = 9;
array[3][0] = 10; array[3][1] = 11; array[3][2] = 12;
```

Lengths of 2D Arrays

A 2D array is actually an array in which each element is a 1D array

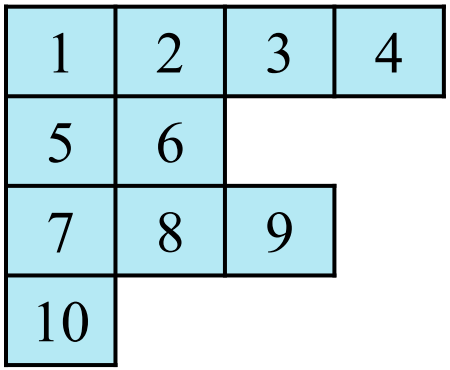
```
int[][] x = new int[3][4];
```

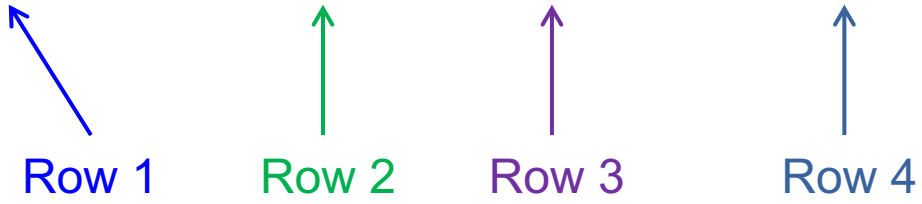


Ragged Arrays

- In 2D arrays, rows can have different lengths (ragged arrays)

```
int[][] a = {{1, 2, 3, 4}, {5, 6}, {7, 8, 9}, {10}};
```





Note that the compiler will **"smartly"** determine the number of rows and columns

Why do we need ragged arrays?

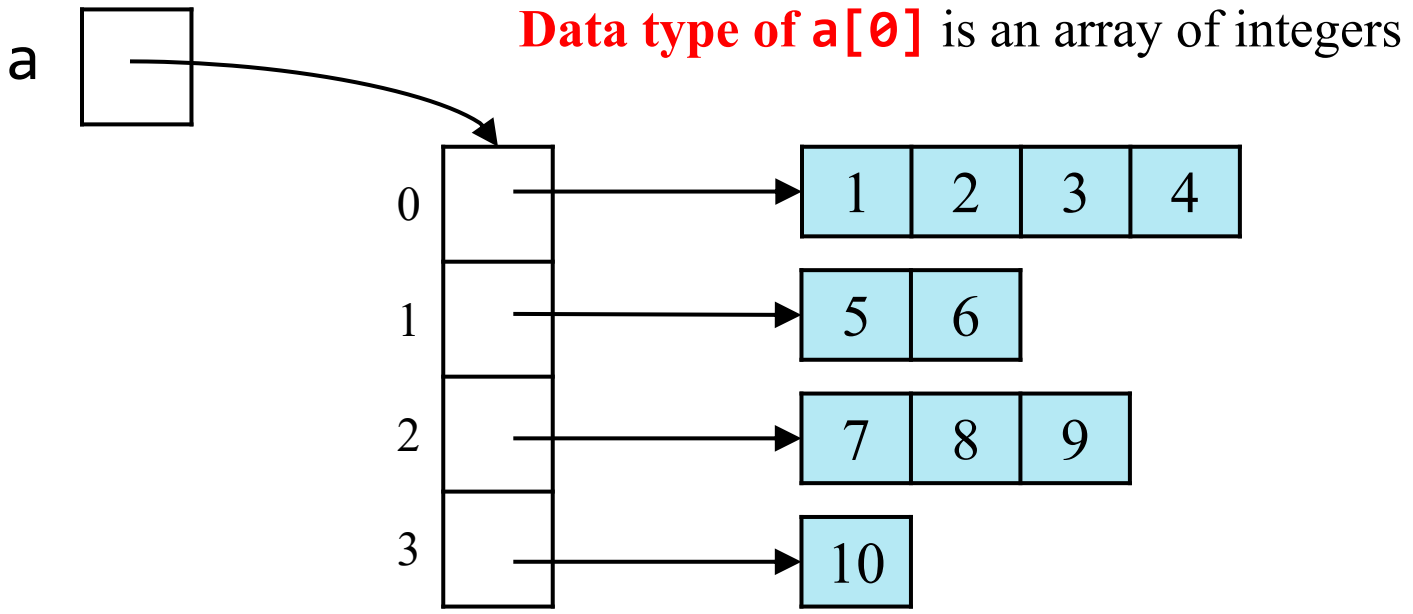
```
1 * 1 = 1
1 * 2 = 2  2 * 2 = 4
1 * 3 = 3  2 * 3 = 6  3 * 3 = 9
1 * 4 = 4  2 * 4 = 8  3 * 4 = 12 4 * 4 = 16
1 * 5 = 5  2 * 5 = 10 3 * 5 = 15 4 * 5 = 20 5 * 5 = 25
1 * 6 = 6  2 * 6 = 12 3 * 6 = 18 4 * 6 = 24 5 * 6 = 30 6 * 6 = 36
1 * 7 = 7  2 * 7 = 14 3 * 7 = 21 4 * 7 = 28 5 * 7 = 35 6 * 7 = 42 7 * 7 = 49
1 * 8 = 8  2 * 8 = 16 3 * 8 = 24 4 * 8 = 32 5 * 8 = 40 6 * 8 = 48 7 * 8 = 56 8 * 8 = 64
1 * 9 = 9  2 * 9 = 18 3 * 9 = 27 4 * 9 = 36 5 * 9 = 45 6 * 9 = 54 7 * 9 = 63 8 * 9 = 72 9 * 9 = 81
```

```
Document:
1. "Hello, how are you?"
2. "I love programming."
3. "Natural language processing is fascinating."

Ragged Array:

[["Hello", "how", "are", "you", "?"],
 ["I", "love", "programming", "."],
 ["Natural", "language", "processing", "is", "fascinating", "."]]
```

Ragged Arrays

- A 2D array is a 1D array of (references to) 1D arrays

```
int[][] a = {{1, 2, 3, 4}, {5, 6}, {7, 8, 9}, {10}};
```



Ragged Arrays

```
int[][] a = {{1, 2, 3, 4}, {5, 6}, {7, 8, 9}, {10}};
```

- What is the value of `a[0]`?
  - Answer: The reference (memory address) to the 1D array {1, 2, 3, 4}
- What is the value of `a.length`?
  - Answer: 4, the number of rows
- What the value of `a[1].length`?
  - Answer: 2, the second row only has 2 columns

Ragged Arrays

- Since a 2D array is a 1D array of (references to) 1D arrays, a 2D array in which each row has a different number of columns can also be created as follows:

```
int[][] 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

b[0][0] = 3;

b[1][2] = 4;
```

Ragged Arrays

- Since a 2D array is a 1D array of (references to) 1D arrays, a 2D array in which each row has a different number of columns can also be created as follows:

```
int[][] b = new int[ 3 ][ ];   // create 2 rows
b[ 0 ] = new int[]{ 1, 2, 3, 4 }; // initialize row 0
b[ 1 ] = new int[]{ 5, 6 }; // initialize row 1
b[ 2 ] = { 7, 8, 9 };       // compilation error!
```

Displaying 2D array

```
public static void main(String[] args) {
    int[][] a = {{1, 2, 3, 4}, {5, 6}, {7, 8, 9}, {10}};



}
```

```
1 2 3 4
5 6
7 8 9
10
```

Displaying 2D array

```
public static void main(String[] args) {
    int[][] a = {{1, 2, 3, 4}, {5, 6}, {7, 8, 9}, {10}};
    // loop through rows
    for(int row = 0; row <          ; row++) {
        // loop through columns
        for(int column = 0; column <              ; column++) {
            System.out.printf("%d ",               );
        }
        System.out.println();
    }
}
```

```
1 2 3 4
5 6
7 8 9
10
```

Displaying 2D array

```
public static void main(String[] args) {
    int[][] a = {{1, 2, 3, 4}, {5, 6}, {7, 8, 9}, {10}};
    // loop through rows
    for(int row = 0; row < a.length; row++) {
        // loop through columns
        for(int column = 0; column < a[row].length; column++) {
            System.out.printf("%d ", a[row][column]);
        }
        System.out.println();
    }
}
```

```
1 2 3 4
5 6
7 8 9
10
```

Computing Average Scores for each student (using foreach statement)

```
public static void main(String[] args) {
    int[][] gradebook = {
        {87, 96, 70, 68, 92},
        {85, 75, 83, 81, 52},
        {69, 77, 96, 89, 72},
        {78, 79, 82, 85, 83}
    };




}
```

```
82.6
75.2
80.6
81.4
```

Computing Average Scores for each student (using foreach statement)

```
public static void main(String[] args) {
    int[][] gradebook = {
        {87, 96, 70, 68, 92},
        {85, 75, 83, 81, 52},
        {69, 77, 96, 89, 72},
        {78, 79, 82, 85, 83}
    };
    for(      grades : gradebook) {
        int sum = 0;



        System.out.printf("%.1f\n", ((double) sum)/grades.length);
    }
}
```

```
82.6
75.2
80.6
81.4
```

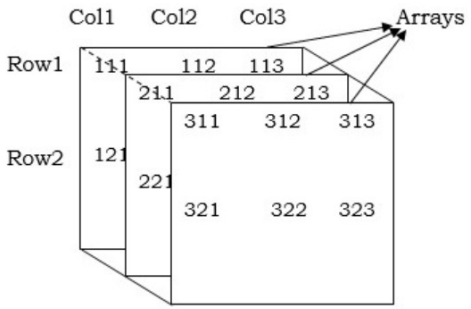
Computing Average Scores for each student (using foreach statement)

```
public static void main(String[] args) {
    int[][] gradebook = {
        {87, 96, 70, 68, 92},
        {85, 75, 83, 81, 52},
        {69, 77, 96, 89, 72},
        {78, 79, 82, 85, 83}
    };
    for(int[] grades : gradebook) {
        int sum = 0;
        for(int grade : grades) {
            sum += grade;
        }
        System.out.printf("%.1f\n", ((double) sum)/grades.length);
    }
}
```

```
82.6
75.2
80.6
81.4
```

Can we move int sum=0 before the for loop?

Multidimensional Arrays



- Arrays can have more than two dimensions.
  - `int[][][] a = new int[3][4][5];`
- Concepts for multidimensional arrays (2D above) can be generalized from 2D arrays
  - 3D array is an 1D array of (references to) 2D arrays, each of which is a 1D array of (references to) 1D arrays
- 1D array and 2D arrays are most commonly-used.

Multidimensional Arrays

An RGB image of m rows and n columns is stored as an 3 x m x n data array that defines red, green, and blue color components for each individual pixel

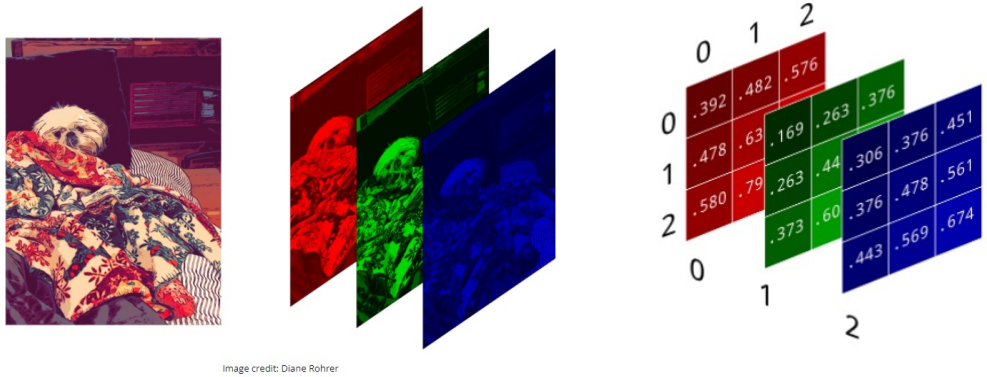


Image: https://www.kdnuggets.com/2019/12/convert-rgb-image-grayscale.html