

Building Java Programs

Chapter 7

Arrays

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Arrays

Reading

- Building Java Programs, Ch. 7.1 - 7.5

Learning Outcomes

- Creating arrays
- Traversing arrays & accessing values
- Array methods
- Common array operations
- Arrays of objects
- Multidimensional arrays
- Object reference behavior

Arrays

- **array**: object that stores many values of the same type.
 - **element**: One value in an array.
 - **index**: A 0-based integer for an element's array position.

index	0	1	2	3	4	5	6	7	8	9
value	12	49	-2	26	5	17	-6	84	72	3

↑				↑					↑	
element 0				element 4					element 9	

Array declaration

type[] **name** = new **type**[**length**];

– Example:

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

Note

- in Java, all array elements must be the same type
- Array length is fixed once the array has been created

index	0	1	2	3	4	5	6	7	8	9
value	0	0	0	0	0	0	0	0	0	0

Quick array initialization

type[] name = {value, value, ... value};

– Example:

```
int[] numbers = {12, 49, -2, 26, 5, 17, -6};
```

index	0	1	2	3	4	5	6
value	12	49	-2	26	5	17	-6

- Useful when you know what the array's elements will be
- The compiler figures out the size by counting the values

Arrays of other types

```
double[] results = new double[5];  
results[2] = 3.4;  
results[4] = -0.5;
```

index	0	1	2	3	4
value	0.0	0.0	3.4	0.0	-0.5

```
boolean[] tests = new boolean[6];  
tests[3] = true;
```

index	0	1	2	3	4	5
value	false	false	false	true	false	false

Array declaration, cont.

- The length can be any integer expression.

```
int x = 2 * 3 + 1;  
int[] data = new int[x %  
5 + 2];
```

- Each element initially gets a "zero-equivalent" value.

Type	Default value
int	0
double	0.0
boolean	false
String or other object	null (means, "no object")

Accessing elements

name[**index**] *// access*
name[**index**] = **value**; *// modify*

– Example:

```
numbers[0] = 27;  
numbers[3] = -6;
```

```
System.out.println(numbers[0]);  
                if (numbers[3] < 0) {  
System.out.println("Element 3 is negative.");  
                }
```

index	0	1	2	3	4	5	6	7	8	9
value	27	0	0	-6	0	0	0	0	0	0

Out-of-bounds

- Legal indexes: between **0** and the **array's length - 1**.
 - Reading or writing any index outside this range will throw an `ArrayIndexOutOfBoundsException`.

- Example:

```
int[] data = new int[10];  
System.out.println(data[0]);           // okay  
System.out.println(data[9]);           // okay  
System.out.println(data[-1]);         // exception  
System.out.println(data[10]);        // exception
```

index	0	1	2	3	4	5	6	7	8	9
value	0	0	0	0	0	0	0	0	0	0

Accessing array elements

```
int[8];
```

```
int[] numbers = new
```

```
numbers[1] = 3;
```

```
numbers[4] = 99;
```

```
numbers[6] = 2;
```

```
int x = numbers[1];
```

```
numbers[x] = 42;
```

```
numbers[numbers[6]] = 11;
```

```
// use numbers[6] as index
```

x

3

	index	0	1	2	3	4	5	6	7
numbers	value	0	4	11	42	99	0	2	0

Arrays and for loops

- It is common to use for loops to access array elements.

```
for (int i = 0; i < 8; i++) {  
    System.out.print(numbers[i] + " ");  
}  
System.out.println();    // output: 0 4 11 0 44 0 0 2
```

- Sometimes we assign each element a value in a loop.

```
for (int i = 0; i < 8; i++) {  
    numbers[i] = 2 * i;  
}
```

index	0	1	2	3	4	5	6	7
value	0	2	4	6	8	10	12	14

The length field

- An array's `length` field stores its number of elements.

name.length

```
for (int i = 0; i < numbers.length; i++) {  
    System.out.print(numbers[i] + " ");  
}  
// output: 0 2 4 6 8 10 12 14
```

– It does not use parentheses like a String's `.length()`.

- Can use `length` to refer to:
 - The last element of an array - **name**[**name**.length-1]
 - The middle element - **name**[**name**.length/2-1]

Limitations of arrays

- You cannot resize an existing array:

```
int[] a = new int[4];  
a.length = 10;           // error
```

- You cannot compare arrays with `==` or `equals`:

```
int[] a1 = {42, -7, 1, 15};  
int[] a2 = {42, -7, 1, 15};  
if (a1 == a2) { ... }           // false!  
if (a1.equals(a2)) { ... }      // false!
```

- An array does not know how to print itself:

```
int[] a1 = {42, -7, 1, 15};  
System.out.println(a1);           // [I@98f8c4]
```

The Arrays class

- Class `Arrays` in package `java.util` has useful static methods for manipulating arrays:

Method name	Description
<code>binarySearch(array, value)</code>	returns the index of the given value in a sorted array (or <code>< 0</code> if not found)
<code>copyOf(array, length)</code>	returns a new copy of an array
<code>equals(array1, array2)</code>	returns <code>true</code> if the two arrays contain same elements in the same order
<code>fill(array, value)</code>	sets every element to the given value
<code>sort(array)</code>	arranges the elements into sorted order
<code>toString(array)</code>	returns a string representing the array, such as <code>"[10, 30, -25, 17]"</code>

Arrays.toString

- `Arrays.toString` accepts an array as a parameter and returns a `String` representation of its elements.

```
int[] e = {0, 2, 4, 6, 8};  
e[1] = e[3] + e[4];  
System.out.println("e is " + Arrays.toString(e));
```

Output:

```
e is [0, 14, 4, 6, 8]
```

– Must import `java.util.*`;

Arrays as parameters

Swapping values

```
public static void main(String[] args) {  
    int a = 7;  
    int b = 35;  
    // swap a with b?  
    a = b;  
    b = a;  
    System.out.println(a + " " + b);  
}
```

– What is wrong with this code? What is its output?

- The red code should be replaced with:

```
int temp = a;  
a = b;  
b = temp;
```


Array reversal question

- Write code that reverses the elements of an array.
 - For example, if the array initially stores:
`[11, 42, -5, 27, 0, 89]`
 - Then after your reversal code, it should store:
`[89, 0, 27, -5, 42, 11]`
 - The code should work for an array of any size.
 - Hint: think about swapping various elements...

Algorithm idea

- Swap pairs of elements from the edges; work inwards:

index	0	1	2	3	4	5
value	89	0	27	-5	42	11



The diagram illustrates a swap operation on an array. Below the array, there are six blue arrows pointing upwards. The first arrow points to the element at index 0 (89), and the last arrow points to the element at index 5 (11). This indicates that the first and last elements of the array are being swapped.

Flawed algorithm

- What's wrong with this code?

```
int[] numbers = [11, 42, -5, 27, 0, 89];  
// reverse the array  
for (int i = 0; i < numbers.length; i++) {  
    int temp = numbers[i];  
    numbers[i] = numbers[numbers.length - 1 - i];  
    numbers[numbers.length - 1 - i] = temp;  
}
```

- The loop goes too far and un-reverses the array! Fixed version:

```
for (int i = 0; i < numbers.length / 2; i++) {  
    int temp = numbers[i];  
    numbers[i] = numbers[numbers.length - 1 - i];  
    numbers[numbers.length - 1 - i] = temp;  
}
```

Array parameter (declare)

```
public static type methodName(type[] name) {
```

- Example:

```
// Returns the average of the given array of numbers.
```

```
public static double average(int[] numbers) {  
    int sum = 0;  
    for (int i = 0; i < numbers.length; i++) {  
        sum += numbers[i];  
    }  
    return (double) sum / numbers.length;  
}
```

- You don't specify the array's length (but you can examine it).

Array parameter (call)

methodName (**arrayName**) ;

- Example:

```
public class MyProgram {  
    public static void main(String[] args) {  
        // figure out the average TA IQ  
        int[] iq = {126, 84, 149, 167, 95};  
        double avg = average(iq);  
        System.out.println("Average IQ = " + avg);  
    }  
    ...  
}
```

– Notice that you don't write the [] when passing the array.

Array return (declare)

```
public static type[] methodName(parameters) {
```

- Example:

```
// Returns a new array with two copies of each value.  
// Example: [1, 4, 0, 7] -> [1, 1, 4, 4, 0, 0, 7, 7]
```

```
public static int[] stutter(int[] numbers) {  
    int[] result = new int[2 * numbers.length];  
    for (int i = 0; i < numbers.length; i++) {  
        result[2 * i] = numbers[i];  
        result[2 * i + 1] = numbers[i];  
    }  
    return result;  
}
```

Array return (call)

type[] name = methodName(parameters) ;

- Example:

```
public class MyProgram {  
    public static void main(String[] args) {  
        int[] iq = {126, 84, 149, 167, 95};  
        int[] stuttered = stutter(iq);  
        System.out.println(Arrays.toString(stuttered));  
    }  
    ...  
}
```

- Output:

[126, 126, 84, 84, 149, 149, 167, 167, 95, 95]

Reference semantics

A swap method?

- Does the following `swap` method work? Why or why not?

```
public static void main(String[] args) {  
    int a = 7;  
    int b = 35;  
    // swap a with b?  
    swap(a, b);  
    System.out.println(a + " " + b);  
}
```

```
public static void swap(int a, int b) {  
    int temp = a;  
    a = b;  
    b = temp;  
}
```

Value semantics

- **value semantics:** Behavior where values are copied when assigned, passed as parameters, or returned.
 - All primitive types in Java use value semantics.
 - When one variable is assigned to another, its value is copied.
 - Modifying the value of one variable does not affect others.

```
int x = 5;  
int y = x;  
y = 17;  
x = 8;
```

```
// x = 5, y = 5  
// x = 5, y = 17  
// x = 8, y = 17
```

Reference semantics (objects)

- **reference semantics:** Behavior where variables actually store the address of an object in memory.
 - When one variable is assigned to another, the object is not copied; both variables refer to the same object.
 - Modifying the value of one variable will affect others.


```
int[] a1 = {4, 15, 8};  
int[] a2 = a1;           // refer to same array as a1  
a2[0] = 7;  
System.out.println(Arrays.toString(a1)); // [7, 15, 8]
```



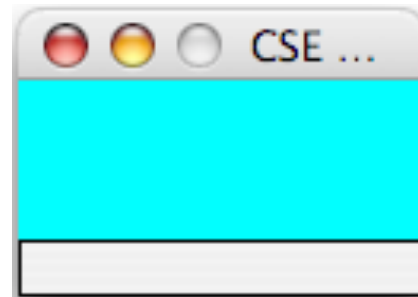
References and objects

- Arrays and objects use reference semantics. Why?
 - efficiency. Copying large objects slows down a program.
 - sharing. It's useful to share an object's data among methods.

```
DrawingPanel panel1 = new DrawingPanel(80, 50);  
DrawingPanel panel2 = panel1;    // same window  
panel2.setBackground(Color.CYAN);
```

panel1  →

panel2  →

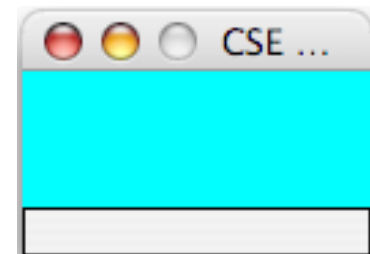
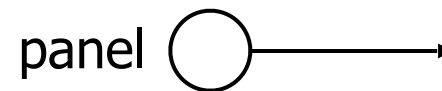
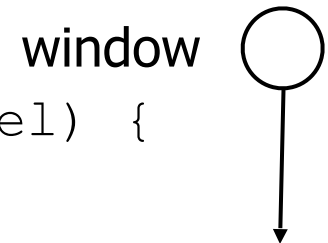


Objects as parameters

- When an object is passed as a parameter, the object is not copied. The parameter refers to the same object.
 - If the parameter is modified, it will affect the original object.

```
public static void main(String[] args) {  
    DrawingPanel window = new DrawingPanel(80, 50);  
    window.setBackground(Color.YELLOW);  
    example(window);  
}
```

```
public static void example(DrawingPanel panel) {  
    panel.setBackground(Color.CYAN);  
    ...  
}
```

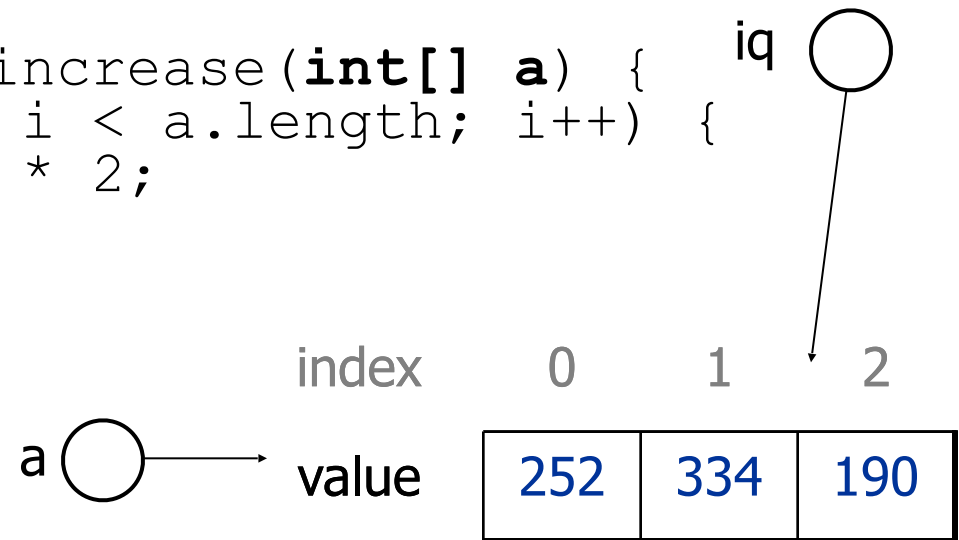


Arrays pass by reference

- Arrays are passed as parameters by reference.
 - Changes made in the method are also seen by the caller.

```
public static void main(String[] args) {  
    int[] iq = {126, 167, 95};  
    increase(iq);  
    System.out.println(Arrays.toString(iq));  
}  
  
public static void increase(int[] a) {  
    for (int i = 0; i < a.length; i++) {  
        a[i] = a[i] * 2;  
    }  
}
```

– Output:
[252, 334, 190]



Array reverse question 2

- Turn your array reversal code into a `reverse` method.
 - Accept the array of integers to reverse as a parameter.

```
int[] numbers = {11, 42, -5, 27, 0, 89};  
reverse(numbers);
```

- Solution:

```
public static void reverse(int[] numbers) {  
    for (int i = 0; i < numbers.length / 2; i++) {  
        int temp = numbers[i];  
        numbers[i] = numbers[numbers.length - 1 -  
i];  
        numbers[numbers.length - 1 - i] = temp;  
    }  
}
```


Array parameter questions

- Write a method `swap` that accepts an arrays of integers and two indexes and swaps the elements at those indexes.

```
int[] a1 = {12, 34, 56};  
swap(a1, 1, 2);  
System.out.println(Arrays.toString(a1));    // [12, 56, 34]
```

- Write a method `swapAll` that accepts two arrays of integers as parameters and swaps their entire contents.
 - Assume that the two arrays are the same length.

```
int[] a1 = {12, 34, 56};  
int[] a2 = {20, 50, 80};  
swapAll(a1, a2);  
System.out.println(Arrays.toString(a1));    // [20, 50, 80]  
System.out.println(Arrays.toString(a2));    // [12, 34, 56]
```

Array parameter answers

// Swaps the values at the given two indexes.

```
public static void swap(int[] a, int i, int j) {  
    int temp = a[i];  
    a[i] = a[j];  
    a[j] = temp;  
}
```

// Swaps the entire contents of a1 with those of a2.

```
public static void swapAll(int[] a1, int[] a2) {  
    for (int i = 0; i < a1.length; i++) {  
        int temp = a1[i];  
        a1[i] = a2[i];  
        a2[i] = temp;  
    }  
}
```

Array return question

- Write a method `merge` that accepts two arrays of integers and returns a new array containing all elements of the first array followed by all elements of the second.

```
int[] a1 = {12, 34, 56};  
int[] a2 = {7, 8, 9, 10};  
int[] a3 = merge(a1, a2);  
System.out.println(Arrays.toString(a3));  
// [12, 34, 56, 7, 8, 9, 10]
```

- Write a method `merge3` that merges 3 arrays similarly.

```
int[] a1 = {12, 34, 56};  
int[] a2 = {7, 8, 9, 10};  
int[] a3 = {444, 222, -1};  
int[] a4 = merge3(a1, a2, a3);  
System.out.println(Arrays.toString(a4));  
// [12, 34, 56, 7, 8, 9, 10, 444, 222, -1]
```

Array return answer 1

```
// Returns a new array containing all elements of a1
// followed by all elements of a2.
public static int[] merge(int[] a1, int[] a2) {
    int[] result = new int[a1.length + a2.length];
    for (int i = 0; i < a1.length; i++) {
        result[i] = a1[i];
    }
    for (int i = 0; i < a2.length; i++) {
        result[a1.length + i] = a2[i];
    }
    return result;
}
```

Array return answer 2

// Returns a new array containing all elements of a1,a2,a3.

```
public static int[] merge3(int[] a1, int[] a2, int[] a3) {  
    int[] a4 = new int[a1.length + a2.length + a3.length];  
    for (int i = 0; i < a1.length; i++) {  
        a4[i] = a1[i];  
    }  
    for (int i = 0; i < a2.length; i++) {  
        a4[a1.length + i] = a2[i];  
    }  
    for (int i = 0; i < a3.length; i++) {  
        a4[a1.length + a2.length + i] = a3[i];  
    }  
    return a4;  
}
```

// Shorter version that calls merge.

```
public static int[] merge3(int[] a1, int[] a2, int[] a3) {  
    return merge(merge(a1, a2), a3);  
}
```

Arrays for tallying

A multi-counter problem

- Problem: Write a method `mostFrequentDigit` that returns the digit value that occurs most frequently in a number.
 - Example: The number 669260267 contains:
one 0, two 2s, four 6es, one 7, and one 9.
`mostFrequentDigit(669260267)` returns 6.
 - If there is a tie, return the digit with the lower value.
`mostFrequentDigit(57135203)` returns 3.

A multi-counter problem

- We could declare 10 counter variables ...

```
int counter0, counter1, counter2, counter3,  
    counter4,  
        counter5, counter6, counter7, counter8,  
    counter9;
```

- But a better solution is to use an array of size 10.
 - The element at index i will store the counter for digit value i .
 - Example for 669260267:

index	0	1	2	3	4	5	6	7	8	9
value	1	0	2	0	0	0	4	1	0	0

- How do we build such an array? And how does it help?

Creating an array of tallies

```
// assume n = 669260267
int[] counts = new int[10];
while (n > 0) {
    // pluck off a digit and add to proper counter
    int digit = n % 10;
    counts[digit]++;
    n = n / 10;
}
```

index	0	1	2	3	4	5	6	7	8	9
value	1	0	2	0	0	0	4	1	0	0

Tally solution

```
// Returns the digit value that occurs most frequently in n.
// Breaks ties by choosing the smaller value.
public static int mostFrequentDigit(int n) {
    int[] counts = new int[10];
    while (n > 0) {
        int digit = n % 10;  // pluck off a digit and tally it
        counts[digit]++;
        n = n / 10;
    }

    // find the most frequently occurring digit
    int bestIndex = 0;
    for (int i = 1; i < counts.length; i++) {
        if (counts[i] > counts[bestIndex]) {
            bestIndex = i;
        }
    }

    return bestIndex;
}
```

Array histogram question

- Given a file of integer exam scores, such as:

```
82
66
79
63
83
```

Write a program that will print a histogram of stars indicating the number of students who earned each unique exam score.

```
85 : *****
86 : *****
87 : ***
88 : *
91 : ****
```

Array histogram answer

```
// Reads a file of test scores and shows a histogram of score distribution.
import java.io.*;
import java.util.*;

public class Histogram {
    public static void main(String[] args) throws FileNotFoundException {
        Scanner input = new Scanner(new File("midterm.txt"));
        int[] counts = new int[101];           // counters of test scores 0 - 100

        while (input.hasNextInt()) {           // read file into counts array
            int score = input.nextInt();
            counts[score]++;                 // if score is 87, then counts[87]++
        }

        for (int i = 0; i < counts.length; i++) {    // print star histogram
            if (counts[i] > 0) {
                System.out.print(i + ": ");
                for (int j = 0; j < counts[i]; j++) {
                    System.out.print("*");
                }
                System.out.println();
            }
        }
    }
}
```

Section attendance question

- Read a file of section attendance (see next slide):

```
yynyyynayayynyyayanyyyaynayyayyanayyyanyayna  
ayyanayyyayanaayyanayyyananayayaynyayayynyna  
yyayaynyyayyanynnyyyayyanayaynannnyyayyayayny
```

- And produce the following output:

```
Section 1  
Student points: [20, 17, 19, 16, 13]  
Student grades: [100.0, 85.0, 95.0, 80.0, 65.0]
```

```
Section 2  
Student points: [17, 20, 16, 16, 10]  
Student grades: [85.0, 100.0, 80.0, 80.0, 50.0]
```

```
Section 3  
Student points: [17, 18, 17, 20, 16]  
Student grades: [85.0, 90.0, 85.0, 100.0, 80.0]
```

- Students earn 3 points for each section attended up to 20.

Section input file

student		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5										
week		1	2	3	4	5	6	7	8	9																																				
section 1		y	y	n	y	y	n	a	y	a	y	y	n	y	y	y	a	y	a	n	y	y	y	a	y	n	a	y	y	a	n	a	y	y	y	a	n	a	y							
section 2		a	y	y	a	n	y	y	y	y	a	y	a	n	a	a	y	y	a	n	a	y	y	y	a	n	a	n	a	y	a	y	a	y	n	y	n	y	a							
section 3		y	y	a	y	a	y	n	y	y	a	y	y	a	n	y	n	n	y	y	y	a	y	y	a	n	a	y	a	y	n	a	n	n	n	y	y	a	y	y	a	y	a	y	n	y

- Each line represents a section.
- A line consists of 9 weeks' worth of data.
 - Each week has 5 characters because there are 5 students.
- Within each week, each character represents one student.
 - a means the student was absent (+0 points)
 - n means they attended but didn't do the problems (+2 points)
 - y means they attended and did the problems (+3 points)

Section attendance answer

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

public class Sections {
    public static void main(String[] args) throws FileNotFoundException {
        Scanner input = new Scanner(new File("sections.txt"));
        int section = 1;
        while (input.hasNextLine()) {
            String line = input.nextLine();           // process one section
            int[] points = new int[5];
            for (int i = 0; i < line.length(); i++) {
                int student = i % 5;
                int earned = 0;
                if (line.charAt(i) == 'y') {           // c == 'y' or 'n' or 'a'
                    earned = 3;
                } else if (line.charAt(i) == 'n') {
                    earned = 2;
                }
                points[student] = Math.min(20, points[student] + earned);
            }
            double[] grades = new double[5];
            for (int i = 0; i < points.length; i++) {
                grades[i] = 100.0 * points[i] / 20.0;
            }
            System.out.println("Section " + section);
            System.out.println("Student points: " + Arrays.toString(points));
            System.out.println("Student grades: " + Arrays.toString(grades));
            System.out.println();
            section++;
        }
    }
}
```

Data transformations

- In many problems we transform data between forms.
 - Example: digits \rightarrow count of each digit \rightarrow most frequent digit
 - Often each transformation is computed/stored as an array.
 - For structure, a transformation is often put in its own method.
- Sometimes we map between data and array indexes.
 - by position (store the i^{th} value we read at index i)
 - tally (if input value is i , store it at array index i)
 - explicit mapping (count 'J' at index 0, count 'X' at index 1)
- Exercise: Modify our Sections program to use static methods that use arrays as parameters and returns.

Array param/return answer

```
// This program reads a file representing which students attended
// which discussion sections and produces output of the students'
// section attendance and scores.

import java.io.*;
import java.util.*;

public class Sections2 {
    public static void main(String[] args) throws FileNotFoundException {
        Scanner input = new Scanner(new File("sections.txt"));
        int section = 1;
        while (input.hasNextLine()) {
            // process one section
            String line = input.nextLine();
            int[] points = countPoints(line);
            double[] grades = computeGrades(points);
            results(section, points, grades);
            section++;
        }

        // Produces all output about a particular section.
        public static void results(int section, int[] points, double[] grades) {
            System.out.println("Section " + section);
            System.out.println("Student scores: " + Arrays.toString(points));
            System.out.println("Student grades: " + Arrays.toString(grades));
            System.out.println();
        }

        ...
    }
}
```

Array param/return answer

...

// Computes the points earned for each student for a particular section.

```
public static int[] countPoints(String line) {  
    int[] points = new int[5];  
    for (int i = 0; i < line.length(); i++) {  
        int student = i % 5;  
        int earned = 0;  
        if (line.charAt(i) == 'y') {           // c == 'y'   or   c == 'n'  
            earned = 3;  
        } else if (line.charAt(i) == 'n') {  
            earned = 2;  
        }  
        points[student] = Math.min(20, points[student] + earned);  
    }  
    return points;  
}
```

// Computes the percentage for each student for a particular section.

```
public static double[] computeGrades(int[] points) {  
    double[] grades = new double[5];  
    for (int i = 0; i < points.length; i++) {  
        grades[i] = 100.0 * points[i] / 20.0;  
    }  
    return grades;  
}
```

```
}
```