Unit 4, Part 1

Arrays

Computer Science S-111
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Collections of Data

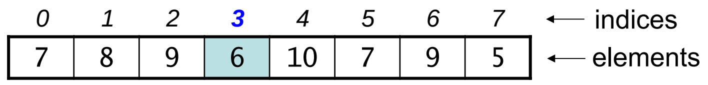
- Recall our program for averaging quiz grades:

```
public static void main(String[] args) {
    Scanner console = new Scanner(System.in);
    int total = 0;
    int numGrades = 0;

    while (true) {
        System.out.print("Enter a grade (or -1 to quit): ");
        int grade = console.nextInt();
        if (grade == -1) {
            break;
        }
        total += grade;
        numGrades++;
    }

    if (numGrades > 0) {
        ...
}
```

- What if we wanted to store the individual grades?
  - an example of a *collection* of data

Arrays

- An *array* is a collection of data values of the same type.
- In the same way that we think of a variable as a single box, an array can be thought of as a sequence of boxes:



- Each box contains one of the data values in the collection
  - referred to as the *elements* of the array
- Each element has a numeric *index*
  - the first element has an index of 0,
    the second element has an index of 1,
    etc.
  - example: the value 6 above has an index of 3
  - like the index of a character in a `String`

Declaring and Creating an Array

- We use a variable to represent the array as a whole.
- Example of declaring an array variable:

```
int[] grades;
```

  - the `[]` indicates that it will represent an array
  - the `int` indicates that the elements will be `int`s
- Declaring the array variable does *not* create the array.
- Example of creating an array:

```
grades = new int[8];
```

the *length* of the array –
i.e., the number of elements

Declaring and Creating an Array (cont.)

- We often declare and create an array in the same statement:

```
int[] grades = new int[8];
```

- General syntax:

  type`[]` *array* `= new` *type*`[`*length*`];`

  where

  type is the type of the individual elements
  array is the name of the variable used for the array
  length is the number of elements in the array

The Length of an Array

- The *length* of an array is the number of elements in the array.
- The length of an array can be obtained as follows:

  array`.length`

  - example:

    ```
    grades.length
    ```

  - note: it is *not* a method

    `grades.length()` won't work!

Auto-Initialization

- When you create an array in this way:

  ```
  int[] grades = new int[8];
  ```

  the runtime system gives the elements default values:

0	1	2	3	4	5	6	7
0	0	0	0	0	0	0	0

- The value used depends on the type of the elements:

`int`	`0`
`double`	`0.0`
`char`	`'\0'`
`boolean`	`false`
objects	`null`

Accessing an Array Element

- To access an array element, we use an expression of the form

  array[*index*]

- Examples:

`grades[0]`	accesses the first element
`grades[1]`	accesses the second element
`grades[5]`	accesses the sixth element

- Here's one way of setting up the array we showed earlier:

0	1	2	3	4	5	6	7
7	8	9	6	10	7	9	5

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

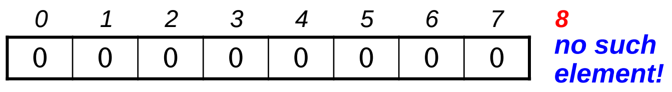
Accessing an Array Element (cont.)

- Acceptable index values:

  integers from 0 to *array*`.length – 1`

- If we specify an index outside that range, we'll get an `ArrayIndexOutOfBoundsException` at runtime.
  - example:

```
int[] grades = int[8];
grades[8] = 5;
```



Accessing an Array Element (cont.)

- The index can be any integer expression.
  - example:

```
int lastGrade = grades[grades.length - 1];
```

- We can operate on an array element in the same way that we operate on any other variable of that type.
  - example: applying a 10% late penalty to the grade at index `i`

```
grades[i] = (int)(grades[i] * 0.9);
```

  - example: adding 5 points of extra credit to the grade at index `i`

```
grades[i] += 5;
```

Another Way to Create an Array

- If we know that we want an array to contain specific values, we can specify them when create the array.
- Example: here's another way to create and initialize our `grades` array:

```
int[] grades = {7, 8, 9, 6, 10, 7, 9, 5};
```

- The list of values is known as an *initialization list*.
  - it can only be specified when the array is declared
  - we don't use the `new` operator in this case
  - we don't specify the length of the array – it is determined from the number of values in the initialization list
- Other examples:

```
double[] heights = {65.2, 72.0, 70.6, 67.9};
boolean[] isPassing = {true, true, false, true};
```

Storing Grades Entered by the User

- We need to know how big to make the array.
  - one way: ask the user for the maximum number of values

```
public static void main(String[] args) {
    Scanner console = new Scanner(System.in);

    System.out.print("How many grades? ");
    int maxNumGrades = console.nextInt();
    int[] grades = new int[maxNumGrades];

    int total = 0;
    int numGrades = 0;

    while (numGrades < maxNumGrades) {
        System.out.print("Enter a grade (or -1 to quit): ");
        grades[numGrades] = console.nextInt();
        if (grades[numGrades] == -1) {
            break;
        }
        total += grades[numGrades];
        numGrades++;
    }
    ...
}
```

Processing the Values in an Array

- We often use a `for` loop to process the values in an array.
- Example: print out all of the grades

```
int[] grades = new int[maxNumGrades];
...
for (int i = 0; i < grades.length; i++) {
    System.out.println("grade " + i + ": " + grades[i]);
}
```

- General pattern:

```
for (int i = 0; i < array.length; i++) {
    do something with array[i];
}
```

- Processing array elements sequentially from first to last is known as *traversing* the array.
  - noun = *traversal*

Another Example of Traversing an Array

- Let's write code to find the highest quiz grade in the array:

```
int max = ____________________;

for (__________; ___________________; ______) {



}
```

Another Example of Traversing an Array (cont.)

`grades` array:

7	8	9	6	10	7	9	5

- Let's trace through our code:

```
int max = grades[0];
for (int i = 1; i < grades.length; i++) {
    if (grades[i] > max) {
        max = grades[i];
    }
}
```

i	grades[i]	max
		7
1	8	8
2	9	9
3	6	9
4	10	10
5	7	10
...		

Review: What Is a Variable?

- We've seen that a variable is like a named "box" in memory that can be used to store a value.

```
int count = 10;
```

count $\boxed{10}$

- If a variable represents a primitive-type value, the value is stored in the variable itself, as shown above.

Reference Variables

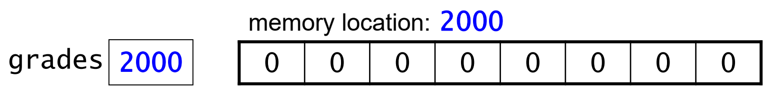
- If a variable represents an object, the object itself is *not* stored inside the variable.
- Rather, the object is located somewhere else in memory, and the variable holds the *memory address* of the object.
    - we say that the variable stores a *reference* to the object
    - such variables are called *reference variables*

Arrays and References

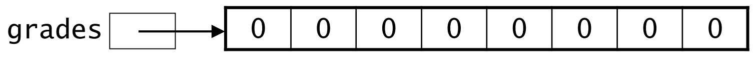
- An array is a type of object.
- Thus, an array variable is a reference variable.
    - it stores a reference to the array
- Example:

```
    int[] grades = new int[8];
```

  might give the following picture:



- We usually use an arrow to represent a reference:



Printing an Array

- What is the output of the following lines?

```
int[] grades = {7, 8, 9, 6, 10, 7, 9, 5};
System.out.println(grades);
```

- To print the contents of the array, we can use a `for` loop as we showed earlier.

- We can also use the `Arrays.toString()` method, which is part of Java's built in `Arrays` class.

```
int[] grades = {7, 8, 9, 6, 10, 7, 9, 5};
System.out.println(Arrays.toString(grades));
```

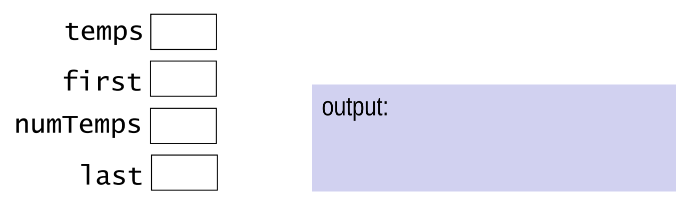
  - doing so produces the following output:

```
[7, 8, 9, 6, 10, 7, 9, 5]
```

- To use this method, we need to import the `java.util` package.

What is the output of the full program?

```
import java.util.*;

public class FunWithArrays {
    public static void main(String[] args) {
        int[] temps = {51, 50, 36, 29, 30};
        int first = temps[0];
        int numTemps = temps.length;
        int last = temps[numTemps - 1];

        temps[2] = 40;
        temps[3] += 5;
        System.out.println(temps[3]);
        System.out.println(Arrays.toString(temps));
    }
}
```

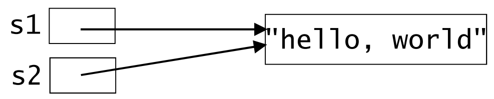


Copying References

- When we assign the value of one reference variable to another, we copy the reference to the object.
  We do *not* copy the object itself.

- Example involving objects:

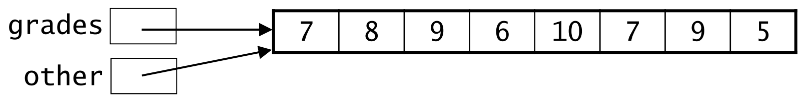
```
String s1 = "hello, world";
String s2 = s1;
```



Copying References (cont.)

- An example involving an array:

```
int[] grades = {7, 8, 9, 6, 10, 7, 9, 5};
int[] other = grades;
```



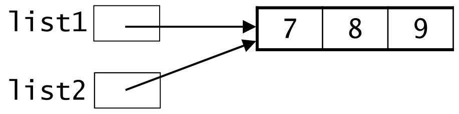
- Given the lines of code above, what will the lines below print?

```
other[2] = 4;
System.out.println(grades[2] + " " + other[2]);
```

Changing the Internals vs. Changing a Variable

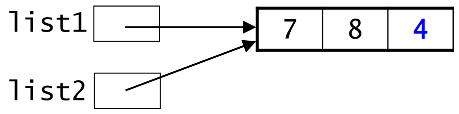
- When two variables hold a reference to the same array...

```
int[] list1 = {7, 8, 9};
int[] list2 = list1;
```



- ...if we change *the internals* of the array, both variables will "see" the change:

```
list2[2] = 4;
System.out.println(Arrays.toString(list1));
```

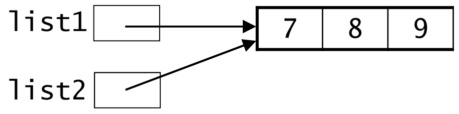


output of println:

Changing the Internals vs. Changing a Variable (cont.)

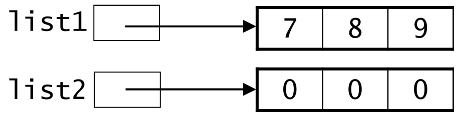
- When two variables hold a reference to the same array...

```
int[] list1 = {7, 8, 9};
int[] list2 = list1;
```



- ...if we change one of the variables *itself*, that does *not* change the other variable:

```
list2 = new int[3];
System.out.println(Arrays.toString(list1));
```



output of println:

Null References

- To indicate that a reference variable doesn't yet refer to any object, we can assign it a special value called `null`.

```
int[] grades = null;
String s = null;
```

grades
null
s
null

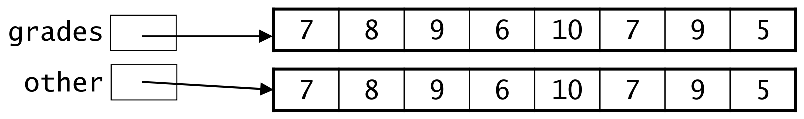
- Attempting to use a null reference to access an object produces a `NullPointerException`.
  - "pointer" is another name for reference
  - examples:

```
int[] grades = null;
String s = null;
grades[3] = 10;        // NullPointerException!
char ch = s.charAt(5); // NullPointerException!
```

Copying an Array

- To actually create a copy of an array, we can:
  - create a new array of the same length as the first
  - traverse the arrays and copy the individual elements
- Example:

```
int[] grades = {7, 8, 9, 6, 10, 7, 9, 5};
int[] other = new int[grades.length];
for (int i = 0; i < grades.length; i++) {
    other[i] = grades[i];
}
```



- What do the following lines print now?

```
other[2] = 4;
System.out.println(grades[2] + " " + other[2]);
```

Programming Style Point

- Here's how we copied the array:

```
int[] grades = {7, 8, 9, 6, 10, 7, 9, 5};
int[] other = new int[grades.length];
for (int i = 0; i < grades.length; i++) {
    other[i] = grades[i];
}
```

- This would also work:

```
int[] grades = {7, 8, 9, 6, 10, 7, 9, 5};
int[] other = new int[8];
for (int i = 0; i < 8; i++) {
    other[i] = grades[i];
}
```

- Why is the first way better?

Passing an Array to a Method

- Let's put our code for finding the highest grade into a method:

```
public class GradeAnalyzer {
    public static _______ maxGrade(int[] grades) {
        int max = grades[0];
        for (int i = 1; i < grades.length; i++) {
            if (grades[i] > max) {
                max = grades[i];
            }
        }

        _____________________;
    }
    public static void main(String[] args) {
        ...
        int maxNumGrades = console.nextInt();
        int[] grades = new int[maxNumGrades];
        ... // code to read in the values
        System.out.println("max grade = " +
          ________________________________);
```

Passing an Array to a Method (cont.)

- What's wrong with this alternative approach?

```
public class GradeAnalyzer {
    public static int maxGrade(int[] grades) {
        int max = grades[0];
        for (int i = 1; i < grades.length; i++) {
            if (grades[i] > max) {
                max = grades[i];
            }
        }

        return max;
    }
    public static void main(String[] args) {
        ...
        int maxNumGrades = console.nextInt();
        int[] grades = new int[maxNumGrades];
        ... // code to read in the values
        maxGrade(grades);
        System.out.println("max grade = " + max);
```

Passing an Array to a Method (cont.)

- We could do this instead:

```
public class GradeAnalyzer {
    public static int maxGrade(int[] grades) {
        int max = grades[0];
        for (int i = 1; i < grades.length; i++) {
            if (grades[i] > max) {
                max = grades[i];
            }
        }

        return max;
    }
    public static void main(String[] args) {
        ...
        int maxNumGrades = console.nextInt();
        int[] grades = new int[maxNumGrades];
        ... // code to read in the values
        int max = maxGrade(grades);
        System.out.println("max grade = " + max);
```

Finding the Average Value in an Array

- Here's a method that computes the average grade:

```
public static double averageGrade(int[] grades) {
    int total = 0;
    for (int i = 0; i < grades.length; i++) {
        total += grades[i];
    }

    return (double)total / grades.length;
}
```

Testing If An Array Meets Some Condition

- Let's say that we need to be able to determine if there are any grades below a certain cutoff value.
  - e.g., to determine if a retest should be given
- Does this method work?

```
public static boolean
anyGradesBelow(int[] grades, int cutoff) {
    for (int i = 0; i < grades.length; i++) {
        if (grades[i] < cutoff) {
            return true;
        } else {
            return false;
        }
    }
}
```

Testing If An Array Meets Some Condition (cont.)

- We can return `true` as soon as we find a grade that is below the threshold.
- We can only return `false` if *none* of the grades is below.
- Here is a corrected version:

```
public static boolean
anyGradesBelow(int[] grades, int cutoff) {
    for (int i = 0; i < grades.length; i++) {
        if (grades[i] < cutoff) {
            return true;
        }
    }

    // if we get here, none of the grades is below.
    return false;
}
```

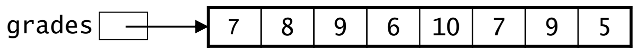
Testing If An Array Meets Some Condition (cont.)

- Here's a similar problem: write a method that determines if all of the grades are perfect (assume perfect = 100).

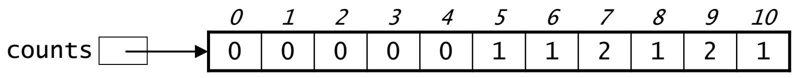
```
public static boolean allPerfect(int[] grades) {











}
```

Using an Array to Count Things

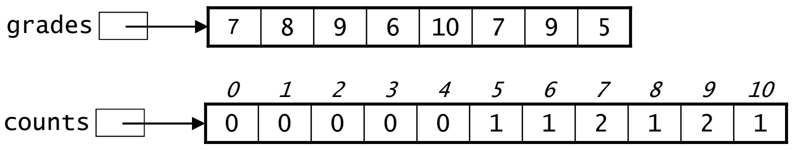
- Let's say that we want to count how many times each of the possible grade values appears in a collection of grades.
- We can use an array to store the counts.
  - `counts[i]` will store the number of times that the grade `i` appears
  - for this grades array



we would have this array of counts:



Using an Array to Count Things (cont.)



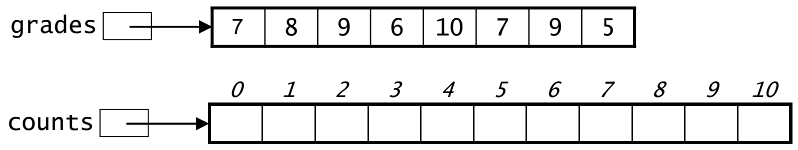
- The size of the `counts` array should be one more than the maximum value being counted:

```
int max = maxGrade(grades);
int[] counts = new int[max + 1];
```

- Given the array, here's how to do the actual counting:

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

Using an Array to Count Things (cont.)



- Let's trace through this code for the grades array shown above:

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

i	grades[i]	operation performed

A Method That Returns an Array

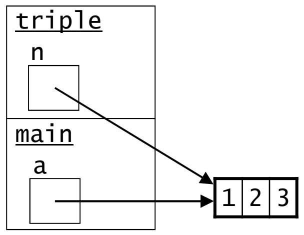
- We can write a method to create and return the array of counts:

```
public static int[] getCounts(int[] grades, int maxGrade) {
    int[] counts = new int[maxGrade + 1];
    for (int i = 0; i < grades.length; i++) {
        counts[grades[i]]++;
    }

    return counts;
}

public static void main(String[] args) {
    ... // main method begins as in the earlier versions
    int max = maxGrade(grades);
    int[] counts = getCounts(grades, max);
    ...
}
```

Using a Method to Change an Array's Contents

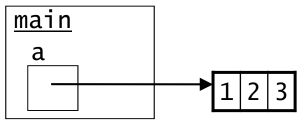
```
public static void main(String[] args) {
    int[] a = {1, 2, 3};
    triple(a);
    System.out.println(Arrays.toString(a));
}

public static void triple(int[] n) {
    for (int i = 0; i < n.length; i++) {
        n[i] = n[i] * 3;
    }
}
```

- When a method is passed an array as a parameter, it gets a copy of the reference, *not* a copy of the array.
- If the method changes the internals of the array, those changes will be there after the method returns.

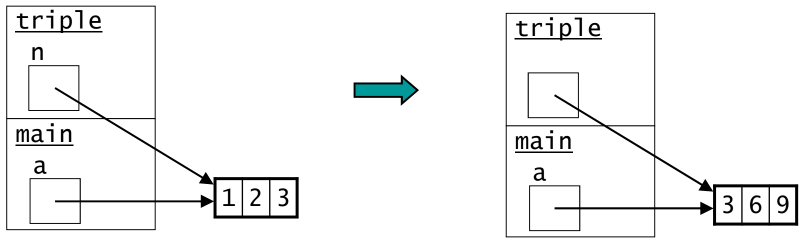


Using a Method to Change an Array's Contents (cont.)

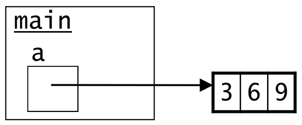
before method call



during method call



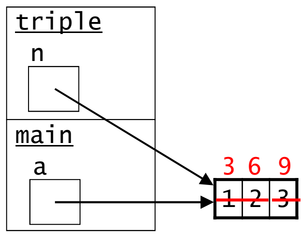
after method call



Changing the Internals vs. Changing a Variable

```
public static void main(String[] args) {
    int[] a = {1, 2, 3};
    triple(a);
    System.out.println(Arrays.toString(a));
}

public static void triple(int[] n) {
    for (int i = 0; i < n.length; i++) {
        n[i] = n[i] * 3;    // changes internals
    }
}
```

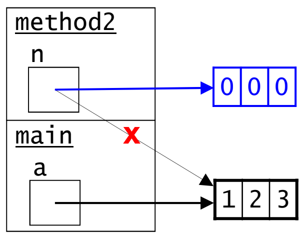
- If the method changes the *internals* of the array, those changes will be there after the method returns.



Changing the Internals vs. Changing a Variable (cont.)

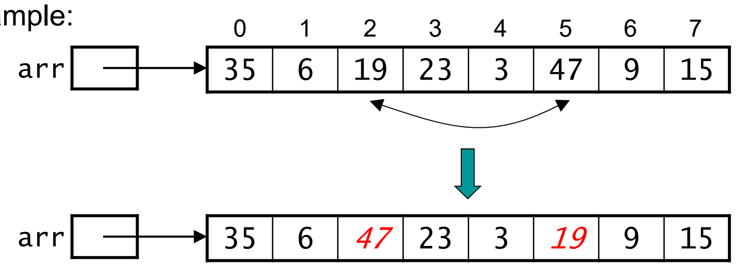
```
public static void main(String[] args) {
    int[] a = {1, 2, 3};
    triple(a);
    System.out.println(Arrays.toString(a));
}

public static void method2(int[] n) {
    n = new int[3];     // changes the variable
}
```

- However, if the method changes its *variable* for the array, that change does *not* affect the original array.
- Changing what's in one variable doesn't affect any other variable!



Swapping Elements in an Array

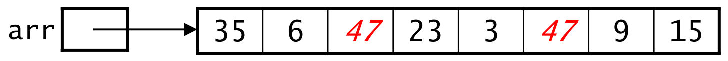
- We sometimes need to be able to swap two elements in an array.
- Example:



- What's wrong with this code for swapping the two values?

```
arr[2] = arr[5];
arr[5] = arr[2];
```

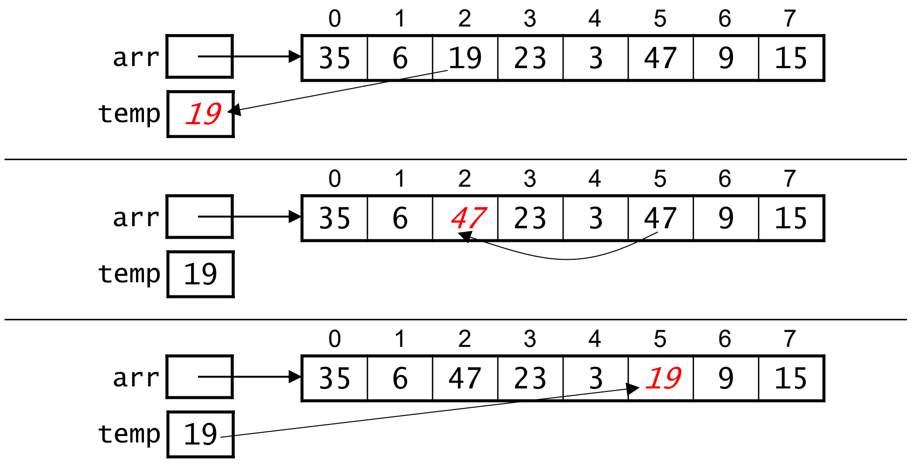
  - it gives this:



Swapping Elements in an Array (cont.)

- To perform a swap, we need to use a temporary variable:

```
int temp = arr[2];
arr[2] = arr[5];
arr[5] = temp;
```



A Method for Swapping Elements

- Here's a method for swapping the elements at positions `i` and `j` in the array `arr`:

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

- We don't need to return anything, because the method changes the internals of the array that is passed in.
- Here's an example of how we would use it:

```
int[] grades = {7, 8, 9, 6, 10, 7, 9, 5};
swap(grades, 2, 5);
System.out.println(Arrays.toString(grades));
```

- What would the output be?

Recall: A Method That Returns an Array

- We can write a method to create and return the array of counts:

```
public static int[] getCounts(int[] grades, int maxGrade) {
    int[] counts = new int[maxGrade + 1];
    for (int i = 0; i < grades.length; i++) {
        counts[grades[i]]++;
    }

    return counts;
}

public static void main(String[] args) {
    ... // main method begins as in the earlier versions
    int max = maxGrade(grades);
    int[] counts = getCounts(grades, max);
    ...
}
```

An Alternative Approach for the Array of Counts

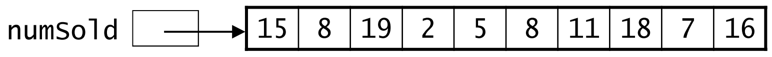
- Create the array ahead of time and pass it into the method:

```
public static void getCounts(int[] grades, int[] counts) {

    for (int i = 0; i < grades.length; i++) {
        counts[grades[i]]++;
    }


}

public static void main(String[] args) {
    ... // main method begins as in the earlier versions
    int max = maxGrade(grades);
    int[] counts = new int[max];
    getCounts(grades, counts);
    ...
}
```

- Because the method changes the internals of the array, those changes will be there after the method returns.

Shifting Values in an Array

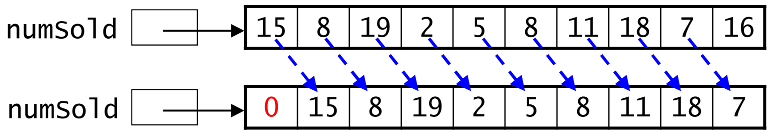
- Let's say a small business is using an array to store the number of items sold over a 10-day period.



`numSold[0]` gives the number of items sold today
`numSold[1]` gives the number of items sold 1 day ago
`numSold[2]` gives the number of items sold 2 days ago
…
`numSold[9]` gives the number of items sold 9 days ago

Shifting Values in an Array (cont.)

- At the start of each day, it's necessary to shift the values over to make room for the new day's sales.



  - the last value is lost, since it's now 10 days old

- In order to shift the values over, we need to perform assignments like the following:

```
numSold[9] = numSold[8];
numSold[6] = numSold[5];
numSold[2] = numSold[1];
```

  - what is the general form (the pattern) of these assignments?

Shifting Values in an Array (cont.)

- Here's one attempt at code for shifting all of the elements:

```
for (int i = 0; i < numSold.length; i++) {
    numSold[i] = numSold[i - 1];
}
```

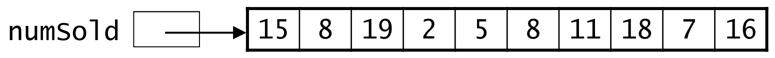
- If we run this, we get an `ArrayIndexOutOfBoundsException`. Why?

Shifting Values in an Array (cont.)

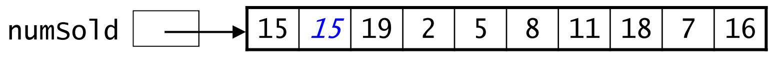
- This version of the code eliminates the exception:

```
for (int i = 1; i < numSold.length; i++) {
    numSold[i] = numSold[i - 1];
}
```

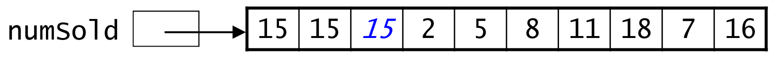
- Let's trace it to see what it does:



  - when `i == 1`, we perform `numSold[1] = numSold[0]` to get:



  - when `i == 2`, we perform `numSold[2] = numSold[1]` to get:



  this obviously doesn't work!

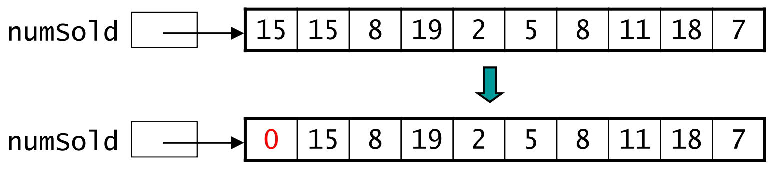
Shifting Values in an Array (cont.)

- How can we fix this code so that it does the right thing?

```
for (int i = 1; i < numSold.length; i++) {
    numSold[i] = numSold[i - 1];
}
```

```
for (                ;                    ;          ) {



}
```

- After performing all of the shifts, we would do: `numSold[0] = 0;`



"Growing" an Array

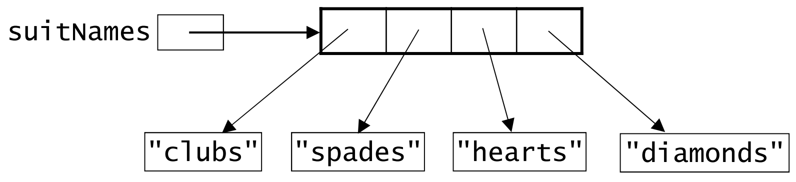
- Once we have created an array, we can't increase its size.
- Instead, we need to do the following:
  - create a new, larger array (use a temporary variable)
  - copy the contents of the original array into the new array
  - assign the new array to the original array variable
- Example for our `grades` array:

```
int[] grades = {7, 8, 9, 6, 10, 7, 9, 5};
...
int[] temp = new int[16];
for (int i = 0; i < grades.length; i++) {
     temp[i] = grades[i];
}
grades = temp;
```

Arrays of Objects

- We can use an array to represent a collection of objects.
- In such cases, the cells of the array store references to the objects.
- Example:

```
String[] suitNames = {"clubs", "spades",
  "hearts", "diamonds"};
```



Two-Dimensional Arrays

- Thus far, we've been looking at single-dimensional arrays
- We can also create *multi-dimensional* arrays.
- The most common type is a two-dimensional (2-D) array.
- We can visualize it as a matrix consisting of rows and columns:

column indices

	0	*1*	*2*	*3*	*4*	*5*	*6*	*7*
0	15	8	3	16	12	7	9	5
1	6	11	9	4	1	5	8	13
2	17	3	5	18	10	6	7	21
3	8	14	13	6	13	12	8	4
4	1	9	5	16	20	2	3	9

row indices

2-D Array Basics

- Example of declaring and creating a 2-D array:

```
int[][] scores = new int[5][8];
```

number of rows

number of columns

- To access an element, we use an expression of the form
  array[*row*][*column*]
  - example: `scores[3][4]` gives the score at row 3, column 4

	0	*1*	*2*	*3*	***4***	*5*	*6*	*7*
0	15	8	3	16	12	7	9	5
1	6	11	9	4	1	5	8	13
2	17	3	5	18	10	6	7	21
3	8	14	13	6	13	12	8	4
4	1	9	5	16	20	2	3	9

Example Application: Maintaining a Game Board

- For a Tic-Tac-Toe board, we could use a 2-D array to keep track of the state of the board:

```
char[][] board = new char[3][3];
```

- Alternatively, we could create *and* initialize it as follows:

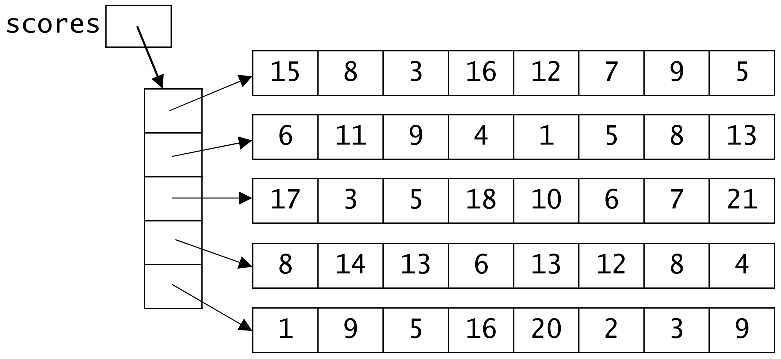
```
char[][] board = {{' ', ' ', ' '},
                  {' ', ' ', ' '},
                  {' ', ' ', ' '}};
```

- If a player puts an X in the middle square, we could record this fact by making the following assignment:

```
board[1][1] = 'X';
```

An Array of Arrays

- A 2-D array is really an array of arrays!



- `scores[0]` represents the entire first row
  `scores[1]` represents the entire second row, etc.

- *array*`.length` gives the number of rows
  array`[`*row*`].length` gives the number of columns in that row

Processing All of the Elements in a 2-D Array

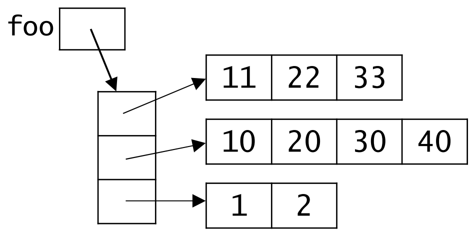
- To perform some operation on all of the elements in a 2-D array, we typically use a nested loop.
  - example: finding the maximum value in a 2-D array.

```
public static int maxValue(int[][] arr) {
    int max = arr[0][0];
    for (int r = 0; r < arr.length; r++) {
        for (int c = 0; c < arr[r].length; c++) {
            if (arr[r][c] > max) {
                max = arr[r][c];
            }
        }
    }

    return max;
}
```

Optional: Other Multi-Dimensional Arrays

- It's possible to have a "ragged" 2-D array in which different rows have different numbers of columns:

```
int[][] foo = {{11, 22, 33},
               {7, 20, 30, 40},
               {1, 2}};
```



- We can also create arrays of higher dimensions.
  - example: a three-dimensional matrix:

```
double[][][] matrix = new double[2][5][4];
```