Arrays

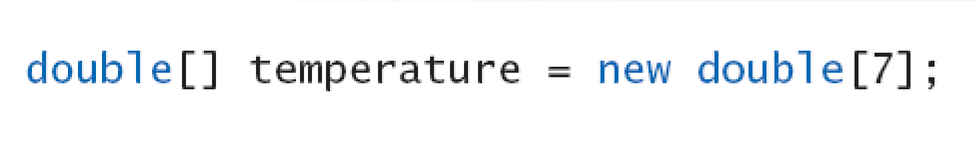
Chapter 7

Array Basics: Outline

- Creating and Accessing Arrays
- Array Details
- The Instance Variable `length`
- More About Array Indices
- Partially-filled Arrays
- Working with Arrays

Creating and Accessing Arrays

- An array is a special kind of object
- Think of it as collection of variables of same type
- Creating an array with 7 variables of type double:



```
double[] temperature = new double[7];
```

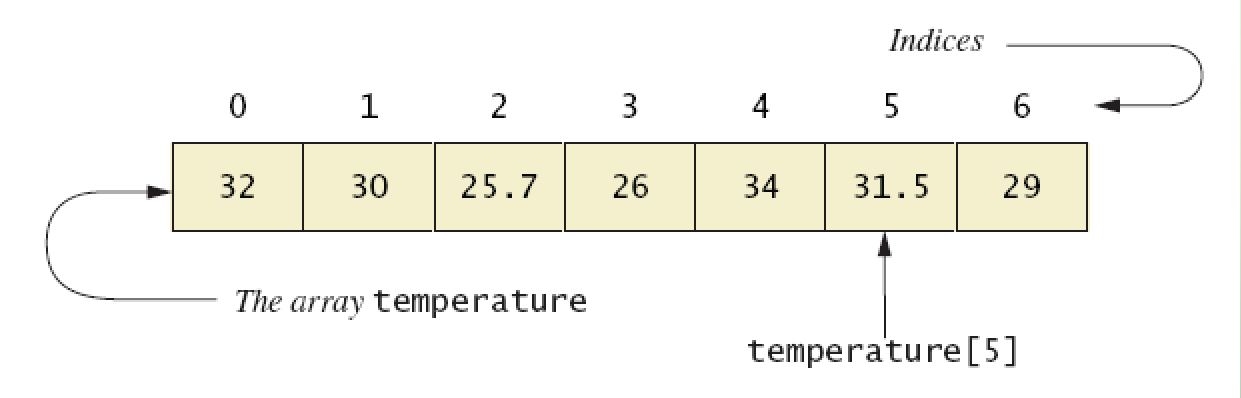
Creating and Accessing Arrays

- To access an element use
  - The name of the array
  - An index number enclosed in braces
- Array indices begin at zero
- Example:

```
double[] temperature = new double[7];
temperature[0] = 25;
temperature[1] = 18;
```

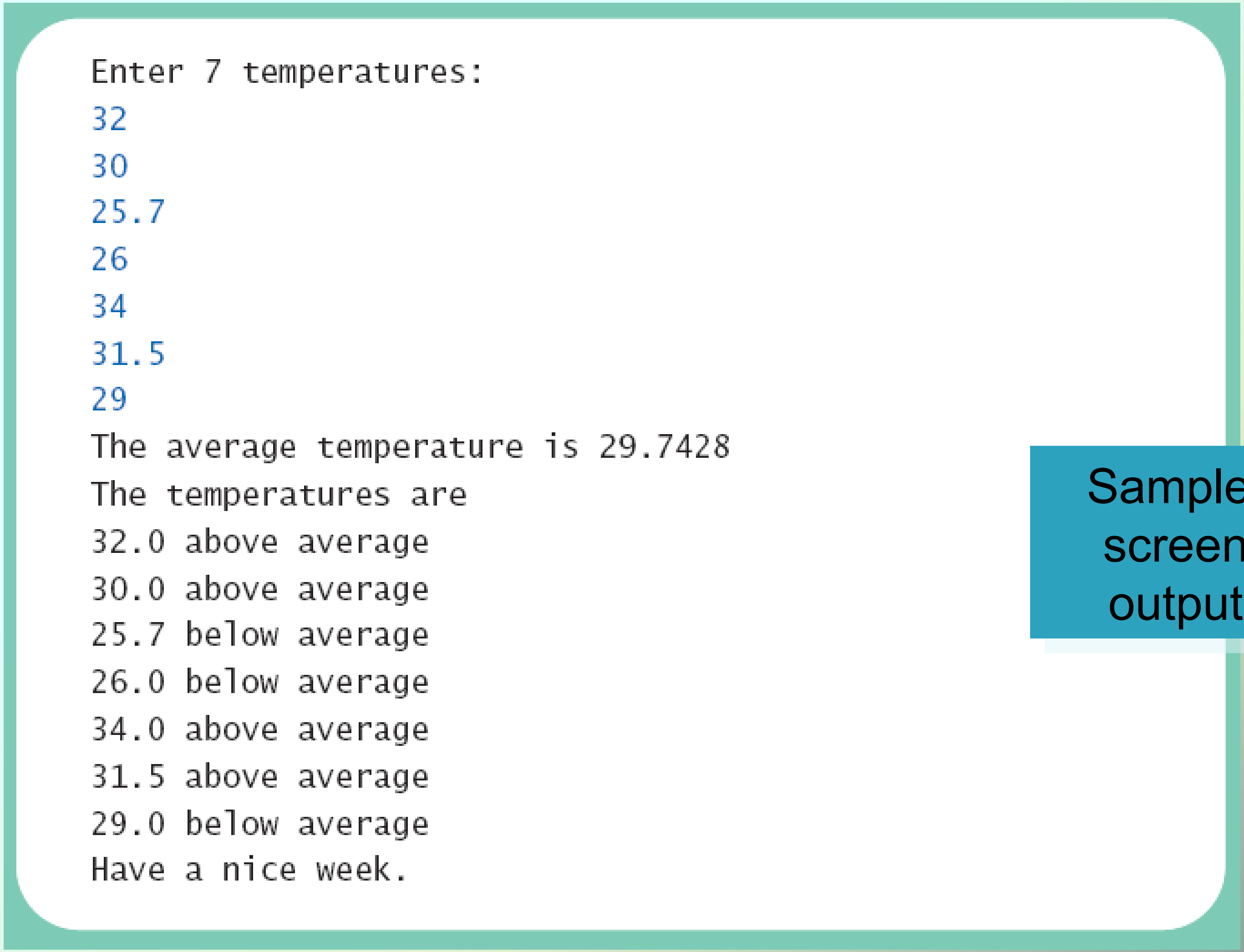
Creating and Accessing Arrays

- Figure 7.1 A common way to visualize an array



- Download and run **ArrayOfTemperatures**

Creating and Accessing Arrays

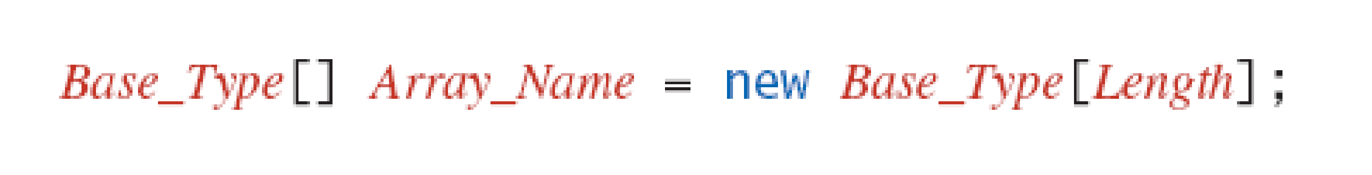


```
Enter 7 temperatures:
32
30
25.7
26
34
31.5
29
The average temperature is 29.7428
The temperatures are
32.0 above average
30.0 above average
25.7 below average
26.0 below average
34.0 above average
31.5 above average
29.0 below average
Have a nice week.
```

Sample screen output

Array Details

- Syntax for declaring an array with **new**



```
Base_Type[] Array_Name = new Base_Type[Length];
```

- The number of elements in an array is its length
- The type of the array elements is the array's base type

Square Brackets with Arrays

- With a data type when declaring an array

```
    int[] pressure;
```

- To enclose an integer expression to declare the length of the array

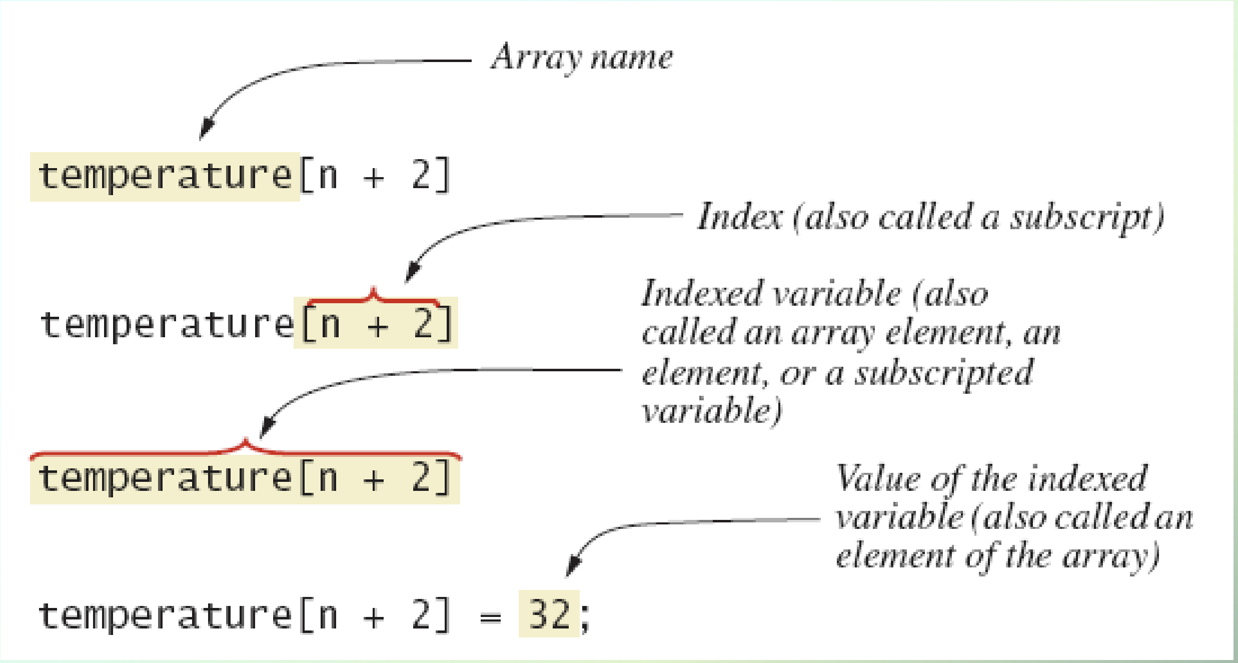
```
    pressure = new int[100];
```

- To name an indexed value of the array

```
    pressure[3] = keyboard.nextInt();
```

Array Details

- Figure 7.2 Array terminology



Array name

```
temperature[n + 2]
```

Index (also called a subscript)

```
temperature[n + 2]
```

Indexed variable (also called an array element, an element, or a subscripted variable)

```
temperature[n + 2]
```

Value of the indexed variable (also called an element of the array)

```
temperature[n + 2] = 32;
```

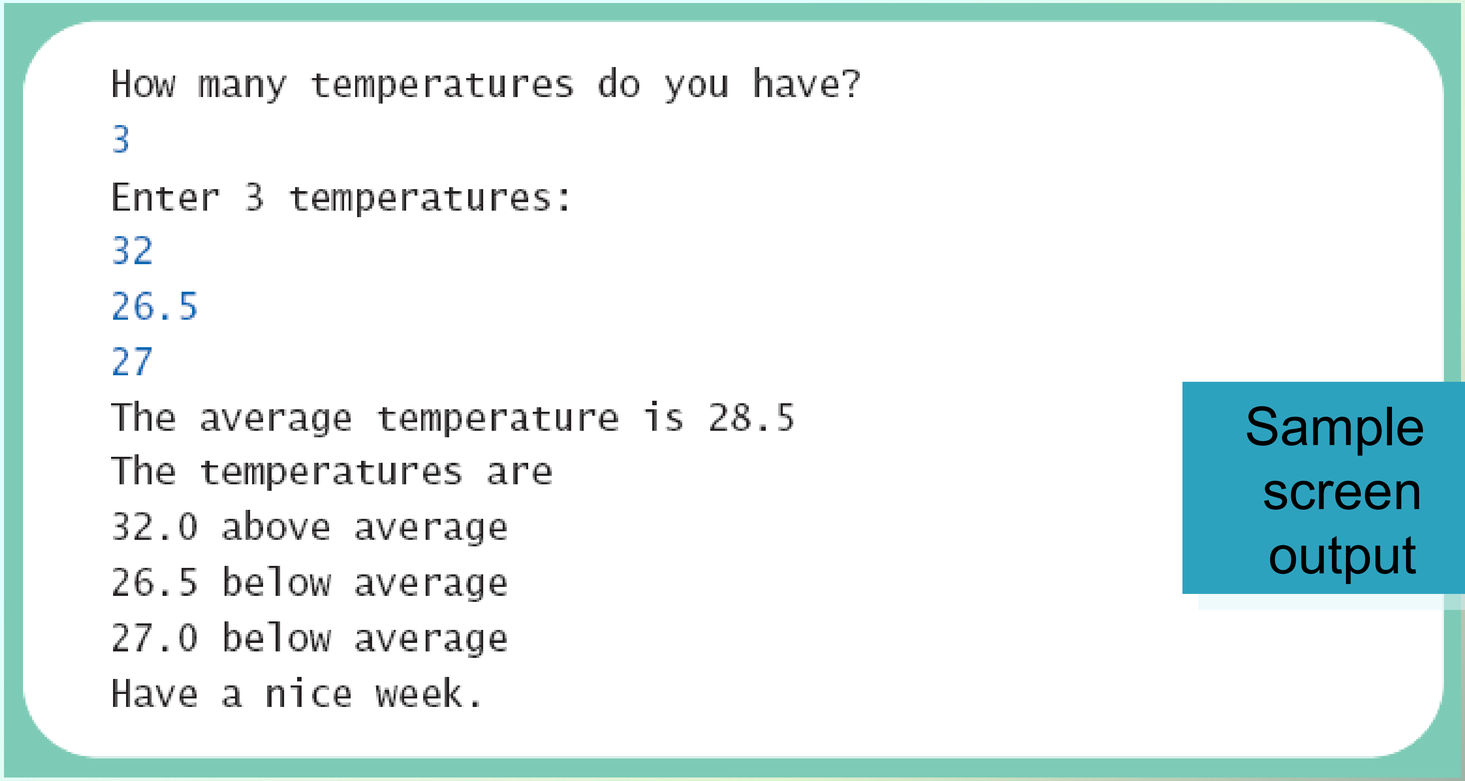
Exercise

- Write a program called **`ArrayStuff`** that declares an array of Strings called **`friends`** with length 4 and fills it with names of your friends
- Use a for-loop to print all 4 elements of your array
- Solution: see **`ArrayStuff1.java`** under Examples link on course website

The Instance Variable `length`

- As an object an array has only one public instance variable
  - Variable `length`
  - Contains number of elements in the array
  - It is final, i.e., value cannot be changed
- Download and run `ArrayOfTemperatures2`

The Instance Variable `length`



```
How many temperatures do you have?
3
Enter 3 temperatures:
32
26.5
27
The average temperature is 28.5
The temperatures are
32.0 above average
26.5 below average
27.0 below average
Have a nice week.
```

Sample screen output

Exercise

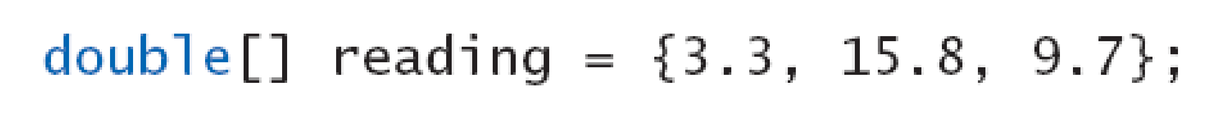
- Modify your **`ArrayStuff`** program to use **`length`** instead of **`4`**
- See **`ArrayStuff2.java`** on Examples link

More About Array Indices

- Index of first array element is 0
- Last valid index is `arrayName.length – 1`
- Array indices must be within bounds to be valid
  - When program tries to access outside bounds, runtime error occurs

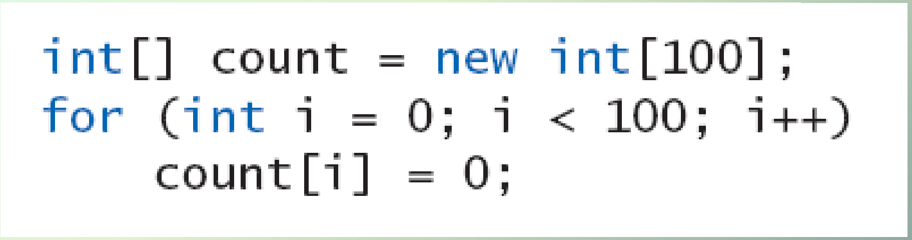
Initializing Arrays

- Possible to initialize at declaration time



```java
double[] reading = {3.3, 15.8, 9.7};
```

- Also may use normal assignment statements
  - One at a time
  - In a loop



```java
int[] count = new int[100];
for (int i = 0; i < 100; i++)
    count[i] = 0;
```

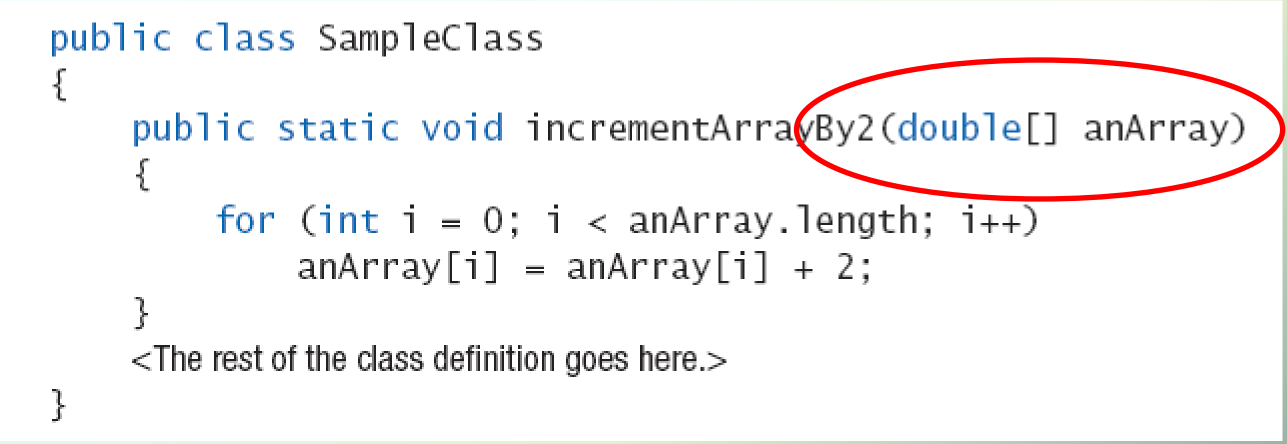
Indexed Variables as Method Arguments

- Indexed variable of an array
  - Example: `a[i]`
  - Can be used anywhere variable of array base type can be used
- Download `ArgumentDemo`
- **Exercise:** Print only those names in your friends array that are more than 5 characters long (use a method that determines whether name fulfills this requirement)

→ Solution: `ArrayStuff3.java`

Entire Arrays as Arguments

- Declaration of array parameter similar to how an array is declared
- Example:



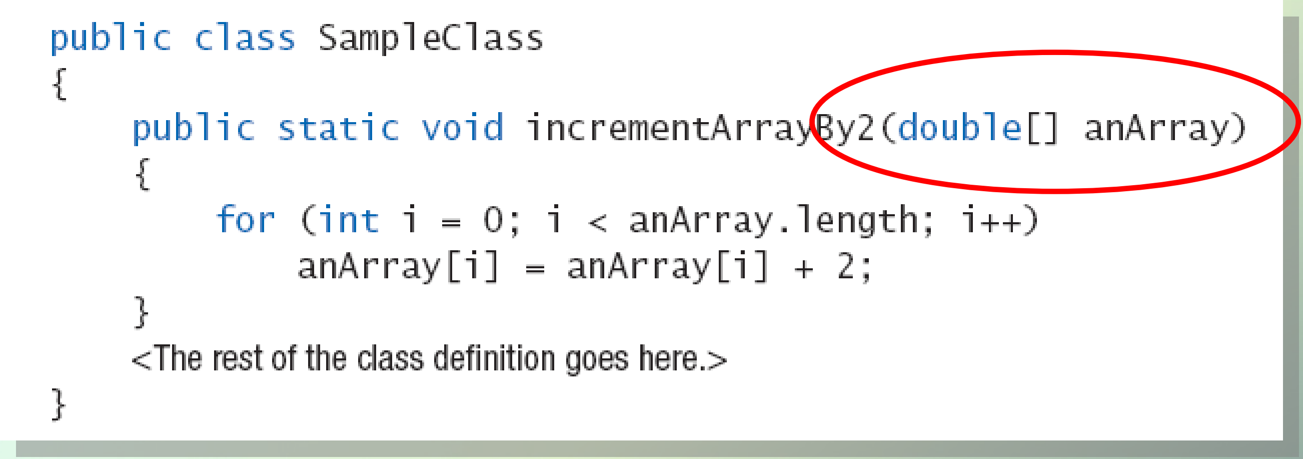
```
public class SampleClass
{
    public static void incrementArrayBy2(double[] anArray)
    {
        for (int i = 0; i < anArray.length; i++)
            anArray[i] = anArray[i] + 2;
    }
    <The rest of the class definition goes here.>
}
```

Entire Arrays as Arguments

- Note: an array parameter in a method heading does not specify the length
  - An array of any length can be passed to the method
  - Inside the method, elements of the array can be changed
- When you pass the entire array, do not use square brackets in the actual argument

Exercise

- Add a method (similar to the one below) to **`ArrayStuff`** called **`printArray`** that takes an array of Strings and prints each element.
- Use **`printArray`** to print **`friends`**



```
public class SampleClass
{
    public static void incrementArrayBy2(double[] anArray)
    {
        for (int i = 0; i < anArray.length; i++)
            anArray[i] = anArray[i] + 2;
    }
    <The rest of the class definition goes here.>
}
```

- Solution: **`ArrayStuff4.java`**

Arguments for Method **`main`**

- Recall heading of method **`main`**

  `public static void main (String[] args)`
- This declares an array
  - Formal parameter named **`args`**
  - Its base type is **`String`**
- Thus possible to pass to the run of a program multiple strings
  - These can then be used by the program

Exercises

- Ex1:
  - Call your `printArray` method with `args`
  - In the interactions pane, type

```
java ArrayStuff5 hello world
```

- Ex2:
  - Write a program called `Adder` that adds all of the numbers in `args` and prints the result
  - Use `Double.parseDouble(String)`
  - In the interactions pane:

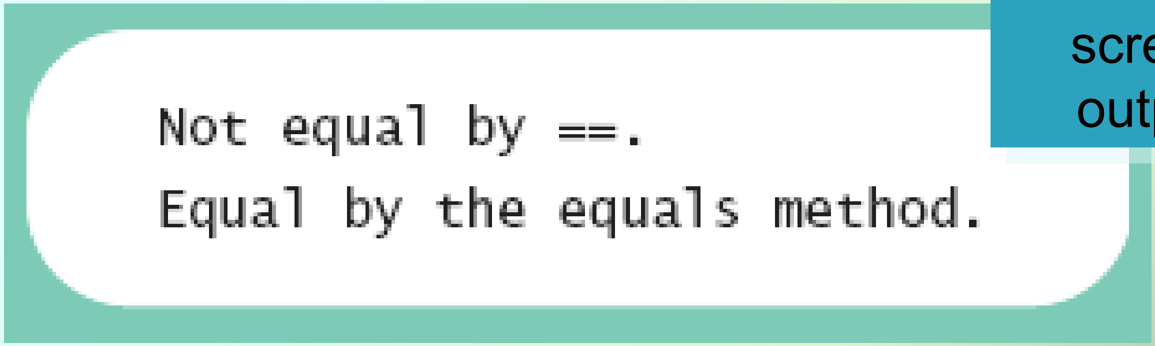
```
java Adder 1 2 3 4 5
```

Array Assignment and Equality

- Arrays are objects
  - Assignment and equality operators behave (misbehave) as specified in previous chapter
- Variable for the array object contains memory address of the object
  - Assignment operator = copies this address
  - Equality operator == tests whether two arrays are stored in same place in memory

Array Assignment and Equality

- Two kinds of equality
- Download **`TestEquals.java`**



```
Not equal by ==.
Equal by the equals method.
```

Sample screen output

Array Assignment and Equality

- Note results of `==`
- Note definition and use of method `equals`
  - Receives two array parameters
  - Checks length and each individual pair of array elements
- Remember: array types are reference types

Methods that Return Arrays

- A Java method may return an array

```
public static int[] add5(int[] anArray)
```

- Download **`ReturnArrayDemo.java`**
- Note definition of return type as an array
- To return the array value
  - Declare a local array
  - Use that identifier in the **`return`** statement

Exercise

Add a method **`copyArray`** to **`ArrayStuff`**:

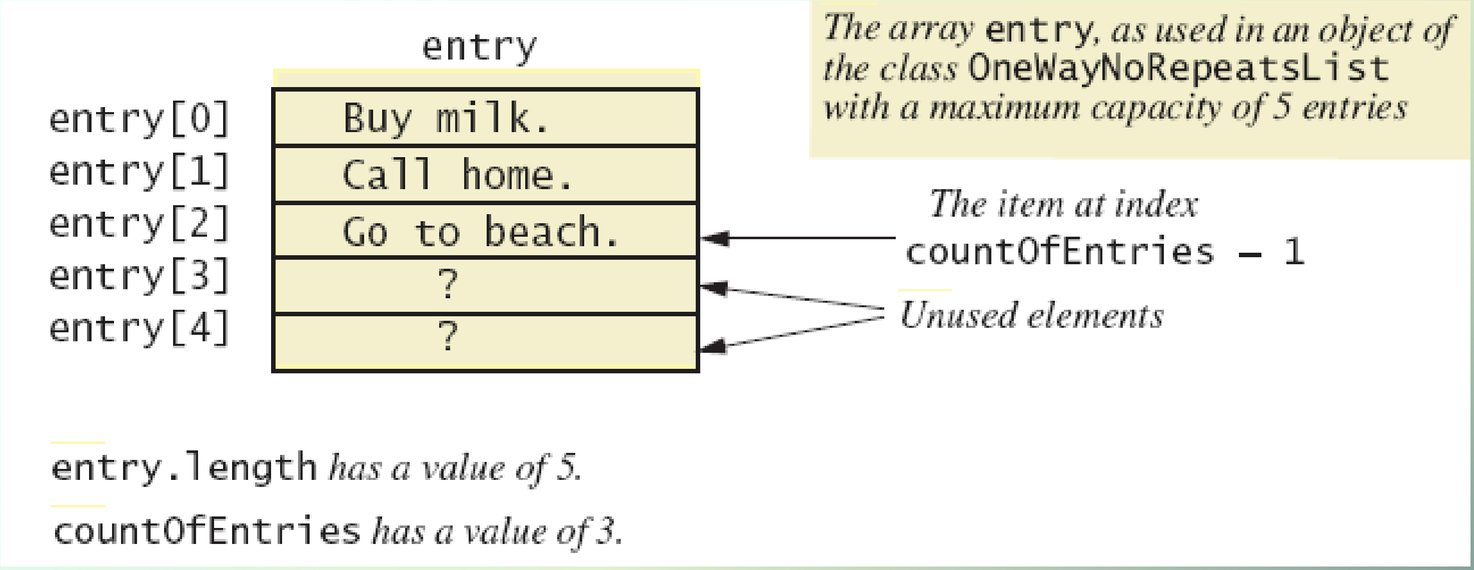
```
public static String[] copyArray(String[] anArray)
{
    // declare array to return
    // copy anArray to return array
    // return the copied array
}
```

Partially Filled Arrays

- Array size specified at definition/creation
    - Can't be changed after that
- Some elements of the array might be empty
    - This is termed a *partially filled array*
- Programmer must keep track of how much of array is used

Partially Filled Arrays

- Download from Examples link:
  - **StringList.java**
  - **StringListDemo.java**



The array entry, *as used in an object of the class* OneWayNoRepeatsList *with a maximum capacity of 5 entries*

The item at index countOfEntries – 1

Unused elements

entry.length *has a value of 5.*

countOfEntries *has a value of 3.*

Searching an Array

- Algorithm used in the `StringList.contains` method is called *sequential search*
  - Looks in order from first to last
  - Good for unsorted arrays
- Search ends when
  - Item is found … or …
  - End of list is reached
- If list is sorted, we could use a more efficient search method

Working with Arrays: Common Tasks

- When working with arrays, there are some operations that need to be performed in many situations.
- These operations include:
  - printing
  - copying
  - resizing
  - removing an element
  - inserting an element

Printing an Array

- Unlike other objects, there is no simple one-liner for printing an entire array.
- You will have to code it using a for-loop:

```
int[] myArray = {4, 6, 2, 3, 7};
for (int i=0; i < myArray.length; i++)
{
    System.out.print(myArray[i] + “ “);
}
System.out.println();
```

Printing an Array

- To print a partially-filled array containing **`numElements`**:

```
int[] myArray;
// partially fill array – increment
// numElements each time an element is
// added
for (int i=0; i < numElements; i++)
{
    System.out.print(myArray[i] + “ “);
}
System.out.println();
```

Copying an Array

- Pseudocode:
  - create a new array of the same length
  - copy each element from **`myArray`** to the new array

```
int[] result = new int[myArray.length];
for (int i=0; i < myArray.length; i++)
{
    result[i] = myArray[i];
}
```

Copying an Array

- To make a copy of only the filled part of the partially-filled array **myArray**, where **numElements** are filled:

```
int[] result = new int[__________];
for (int i=0; i < __________; i++)
{
    result[i] = myArray[i];
}
```

Copying an Array

- To make a copy of only the filled part of the partially-filled array **myArray**, where **numElements** are filled:

```
int[] result = new int[numElements];
for (int i=0; i < numElements; i++)
{
    result[i] = myArray[i];
}
```

Resizing an Array

- When you need to add another element to a full array, **resize** it.
- Resizing just means making the array bigger by some amount.

Resizing an Array

- Pseudocode:
  - create a new array **`amount`** larger than **`myArray`**
  - copy all elements from **`myArray`** to new array
  - make **`myArray`** reference the new array

```
int[] result = new int[myArray.length + amount];
for (int i=0; i < myArray.length; i++) {
     result[i] = myArray[i];
}
myArray = result;
```

Removing an Element from an Array

- Pseudocode:
  - create a new array 1 smaller than **`myArray`**
  - copy before **`index`** from **`myArray`** to new array
  - copy elements after **`index`** to new array (at **`index-1`**)
  - make **`myArray`** reference the new array

Removing an Element from an Array

- Fill in the blanks:

```
int[] result = new int[myArray.length-1];
// copy elements before index
for (int i=0; i < index; i++)
{
   result[i] = myArray[i];
}
// copy elements after index
for (int i=index+1; i < myArray.length; i++)
{
   result[____] = myArray[___];
}
myArray = result;
```

Removing an Element from an Array

```
int[] result = new int[myArray.length-1];
// copy elements before index
for (int i=0; i < index; i++)
{
   result[i] = myArray[i];
}
// copy elements after index
for (int i=index+1; i < myArray.length; i++)
{
   result[i-1] = myArray[i];
}
myArray = result;
```

Inserting an Element into an Array

- Pseudocode:
  - create a new array 1 bigger than `myArray`
  - copy elements before `index` from `myArray` to new array
  - insert element at index
  - copy elements after `index` to new array (at `index+1`)
  - make `myArray` reference the new array

Inserting an Element into an Array

- Fill in the blanks:

```
int[] result = new int[myArray.length+1];
// copy elements before index
for (int i=0; i < index; i++)
{
   result[i] = myArray[i];
}

result[index] = elementToInsert;
// copy elements after index
for (int i=index; i < myArray.length; i++)
{
   result[____] = myArray[___];
}
myArray = result;
```

Inserting an Element into an Array

```
int[] result = new int[myArray.length+1];
// copy elements before index
for (int i=0; i < index; i++)
{
    result[i] = myArray[i];
}

result[index] = elementToInsert;
// copy elements after index
for (int i=index; i < myArray.length; i++)
{
    result[i+1] = myArray[i];
}
myArray = result;
```

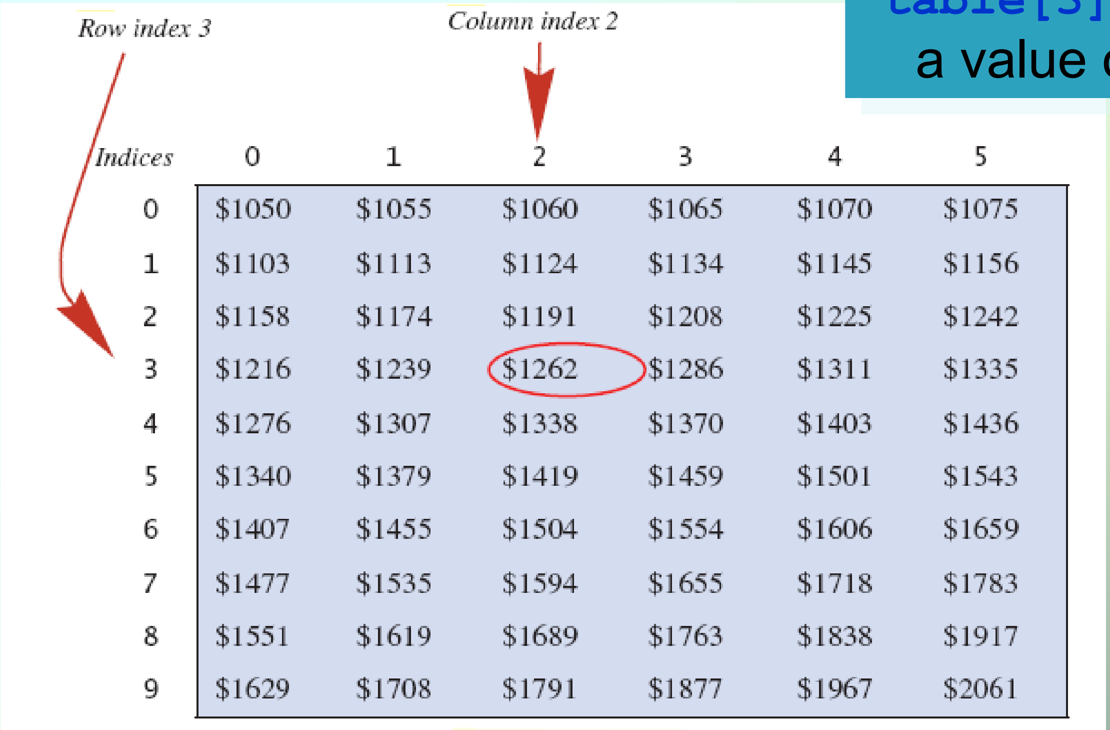
Multidimensional Arrays: Outline

- Multidimensional-Array Basics
- Multidimensional-Array Parameters and Returned Values
- Java's Representation of Multidimensional Ragged Arrays
- Programming Examples:
  - Employee Time Records
  - Levenshtein Distance Algorithm

Multidimensional-Array Basics

- Figure 7.7 Row and column indices for an array named **`table`**

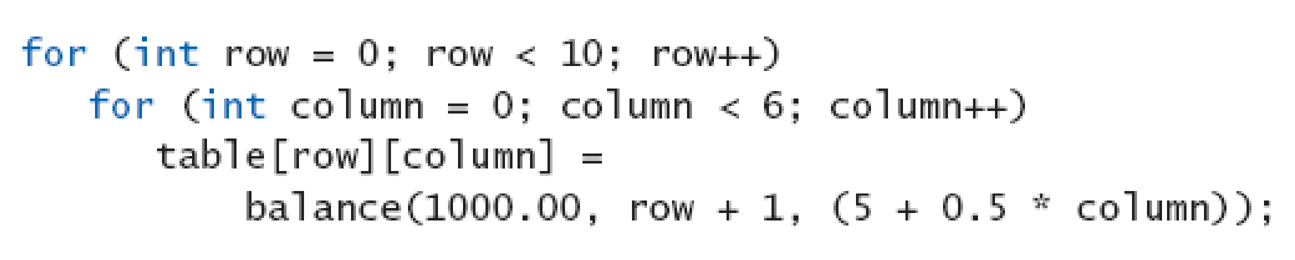
`table[3][2]` has a value of 1262


Row index 3
Column index 2

Indices	0	1	2	3	4	5
0	$1050	$1055	$1060	$1065	$1070	$1075
1	$1103	$1113	$1124	$1134	$1145	$1156
2	$1158	$1174	$1191	$1208	$1225	$1242
3	$1216	$1239	$1262	$1286	$1311	$1335
4	$1276	$1307	$1338	$1370	$1403	$1436
5	$1340	$1379	$1419	$1459	$1501	$1543
6	$1407	$1455	$1504	$1554	$1606	$1659
7	$1477	$1535	$1594	$1655	$1718	$1783
8	$1551	$1619	$1689	$1763	$1838	$1917
9	$1629	$1708	$1791	$1877	$1967	$2061

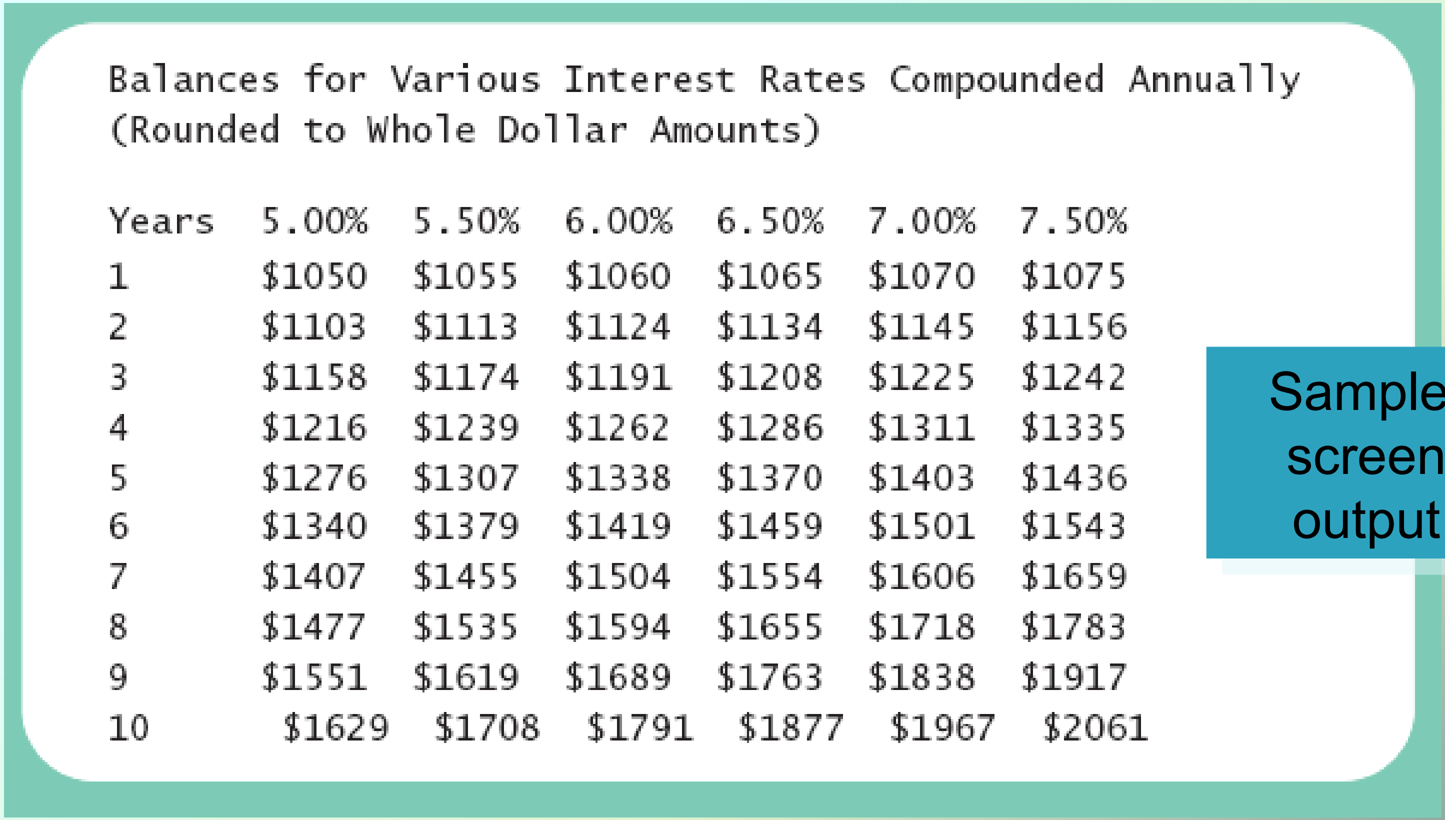
Multidimensional-Array Basics

- Download **`InterestTable.java`**
- We can access elements of the table with a nested for loop
- Example:



```
for (int row = 0; row < 10; row++)
   for (int column = 0; column < 6; column++)
      table[row][column] =
          balance(1000.00, row + 1, (5 + 0.5 * column));
```

Multidimensional-Array Basics



```
Balances for Various Interest Rates Compounded Annually
(Rounded to Whole Dollar Amounts)

Years  5.00%  5.50%  6.00%  6.50%  7.00%  7.50%
1      $1050  $1055  $1060  $1065  $1070  $1075
2      $1103  $1113  $1124  $1134  $1145  $1156
3      $1158  $1174  $1191  $1208  $1225  $1242
4      $1216  $1239  $1262  $1286  $1311  $1335
5      $1276  $1307  $1338  $1370  $1403  $1436
6      $1340  $1379  $1419  $1459  $1501  $1543
7      $1407  $1455  $1504  $1554  $1606  $1659
8      $1477  $1535  $1594  $1655  $1718  $1783
9      $1551  $1619  $1689  $1763  $1838  $1917
10      $1629  $1708  $1791  $1877  $1967  $2061
```

Sample screen output

Multidimensional-Array Parameters and Returned Values

- Methods can have
  - Parameters that are multidimensional-arrays

```
public static void printTable(int[][] table) {
...
}
```

  - Return values that are multidimensional-arrays

```
public static int[][] copyTable(int[][] table) {
...
}
```

- Download `InterestTable2.java`

Java's Representation of Multidimensional Arrays

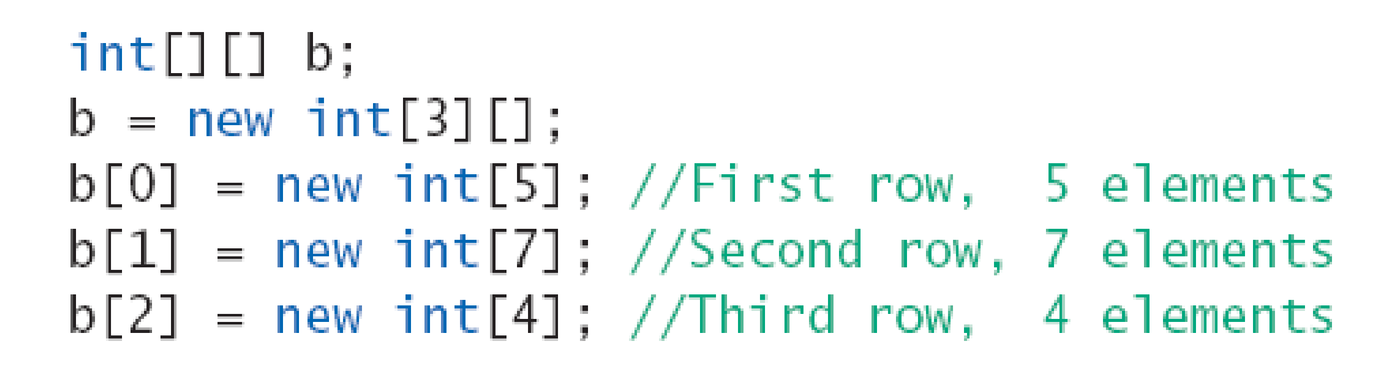
- Multidimensional array represented as several one-dimensional arrays
- Given

```
int [][] table = new int [10][6];
```

- Array table is actual a 1 dimensional array of length 10, with base type `int[]`
  - It is an array of arrays
- Important when sequencing through multidimensional array

Ragged Arrays

- Not necessary for all rows to be of the same length
- Example:



```
int[][] b;
b = new int[3][];
b[0] = new int[5]; //First row,  5 elements
b[1] = new int[7]; //Second row, 7 elements
b[2] = new int[4]; //Third row,  4 elements
```

Printing 2D Arrays

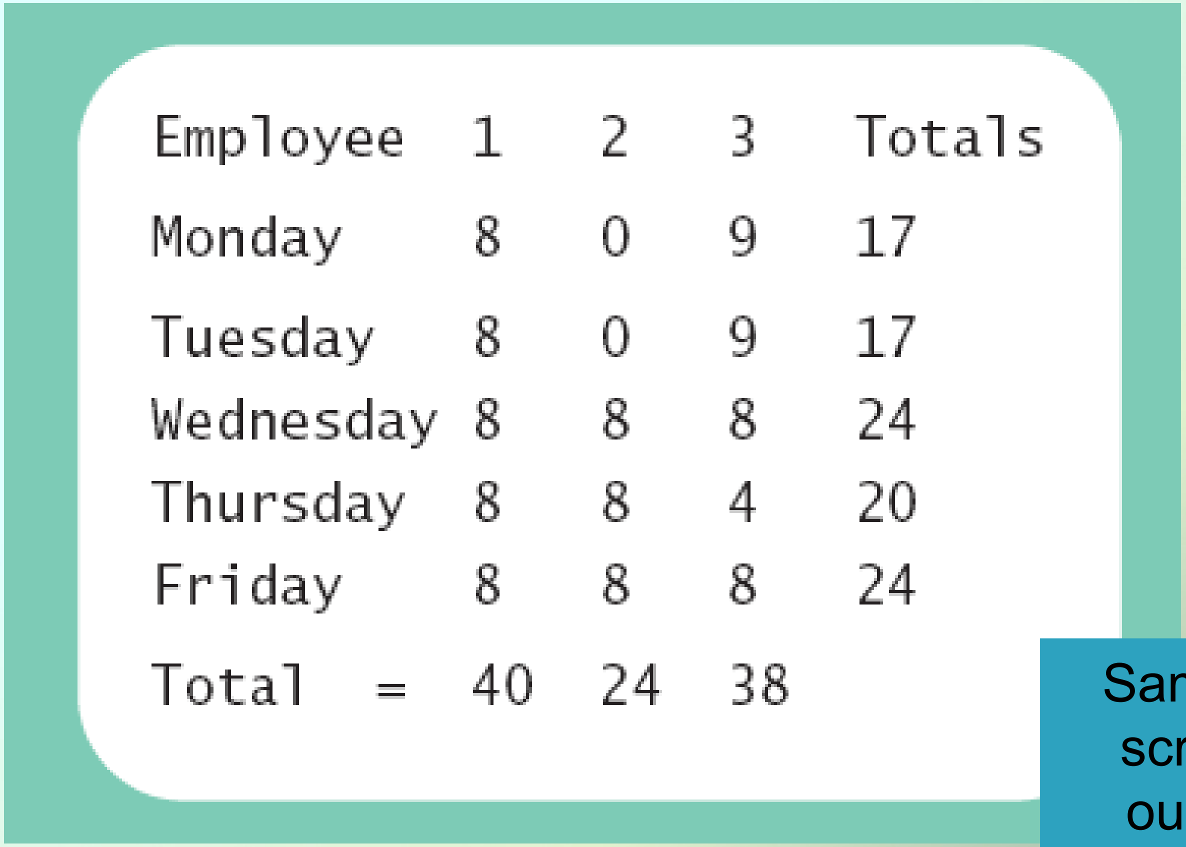
- Use **`table.length`** and **`table[row].length`**
- Outer loop iterates the rows
- Inner loop iterates columns in current row

```
public static void printArray(int[][] table)
{
  for (int row=0; row < table.length; row++)
  {
    for (int col=0; col < table[row].length; col++)
    {
      System.out.print(table[row][col]);
    }
    System.out.println();
  }
}
```

Another Example with Multidimensional-Arrays

- Employee Time Records
  - Two-dimensional array stores hours worked
    - For each employee
    - For each of 5 days of work week
    - Array is private instance variable of class
- Download `TimeBook.java`
- Run it and familiarize yourself with the program

Another Example with Multidimensional-Arrays

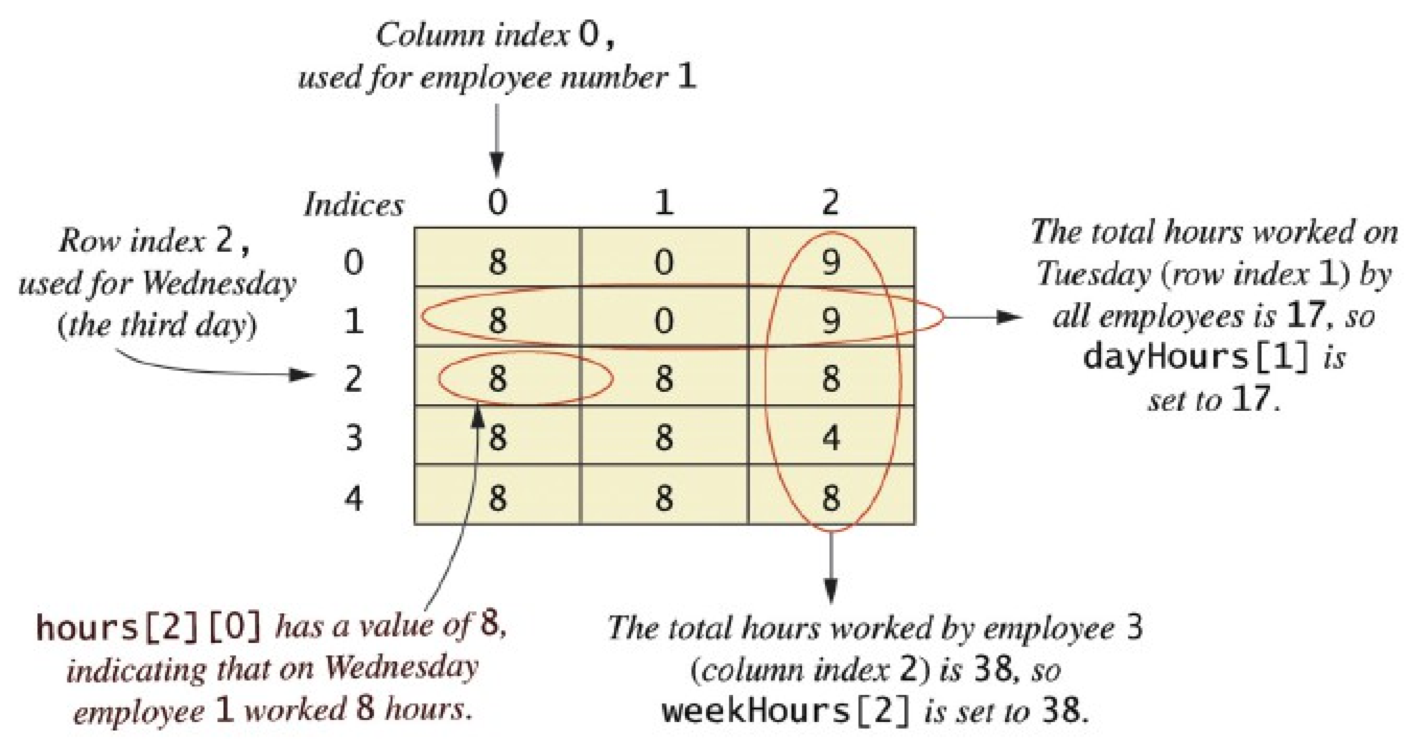


```
Employee  1   2   3   Totals

Monday    8   0   9   17

Tuesday   8   0   9   17
Wednesday 8   8   8   24
Thursday  8   8   4   20
Friday    8   8   8   24

Total   = 40  24  38
```

Sample screen output

Another Example with Multidimensional-Arrays

- Figure 7.8 Arrays for the class **`TimeBook`**



Column index 0, *used for employee number* 1

Indices	0	1	2
0	8	0	9
1	8	0	9
2	8	8	8
3	8	8	4
4	8	8	8

Row index 2, *used for Wednesday (the third day)*

The total hours worked on Tuesday (row index 1*) by all employees is* 17, *so* `dayHours[1]` *is set to* 17.

`hours[2][0]` *has a value of* 8, *indicating that on Wednesday employee* 1 *worked* 8 *hours.*

The total hours worked by employee 3 *(column index* 2*) is* 38, *so* `weekHours[2]` *is set to* 38.

Levenshtein Distance

- Vladimir Levenshtein
  - Works at the Keldysh Institute of Applied Mathematics in Moscow
- Levenshtein Distance Algorithm
  - developed in 1965
  - used to measure the difference (distance) between 2 strings
  - useful in applications (spell checkers, DNA sequence comparisons) to determine how similar 2 strings are

Levenshtein Distance

- The lower the distance, the more similar the 2 input words are.
  - stop, shop (1)
  - power, owner (2)
  - task, program (7)

Levenshtein Distance

- The distance between 2 strings is determined by the minimum number of operations needed to transform one string into the other
- Operations:
  - **insertion**
  - **deletion**
  - **substitution** of a single character

Levenshtein Distance - Examples

- distance between "kitten" and "sitting" is 3

  kitten -> sitten (substitute 's' for 'k')
  sitten -> sittin (substitute 'i' for 'e')
  sittin -> sitting (insert 'g' at the end)

- distance between "ape" and "face" is 2

  ape -> fape (insert 'f')
  fape -> face (substitute 'c' for 'p')

Levenshtein Distance - Algorithm

- Find the distance between **s1** ("ape") and **s2** ("face")
- Create a table one element longer than s1 and one element wider than s2

```
int[][] distTable = new int[s1.length()+1][s2.length()+1];
```

		f	a	c	e
a					
p					
e					

Levenshtein Distance - Algorithm

- Initialize column 0

```
 for (int i=0; i<distTable.length; i++)
{

    distTable[i][0] = i;

}
```

		f	a	c	e
	0				
a	1				
p	2				
e	3				

Levenshtein Distance - Algorithm

- Initialize row 0

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

		f	a	c	e
	0	1	2	3	4
a	1				
p	2				
e	3				

Levenshtein Distance - Algorithm

- Each operation (insert, delete, substitute) has an associated cost
  - Insertion cost: 1
  - Deletion cost: 1
  - Substitution cost:
    - 0 if the characters are the same
    - 1 if the characters are different

Levenshtein Distance - Algorithm

- The rest of the table is filled in as follows:

aboveLeft	above
left	min(left + insert, above + delete, aboveLeft + subst)

Levenshtein Distance - Algorithm

Element [1][1]

left: 1

above: 1

leftAbove: 0

substCost: 1 (f != a)

min(left+1,

above+1,

leftAbove + substCost)

min(2, 2, **1**)

		f	a	c	e
	0	1	2	3	4
a	1	1			
p	2				
e	3				

Levenshtein Distance - Algorithm

Element [1][2]

left: 1

above: 2

leftAbove: 1

substCost: 0 (a == a)

```
min(left+1,
    above+1,
    leftAbove + substCost)
```

min(2, 3, **1**)

		f	a	c	e
	0	1	2	3	4
a	1	1	1		
p	2				
e	3				

Levenshtein Distance - Algorithm

Element [1][3]

left: 1

above: 3

leftAbove: 2

substCost: 1 (c != a)

min(left+1,
    above+1,
    leftAbove + substCost)

min(2, 4, 3)

		f	a	c	e
	0	1	2	3	4
a	1	1	1	2	
p	2				
e	3				

Levenshtein Distance - Algorithm

Element [1][4]

left: 2

above: 4

leftAbove: 3

substCost: 1 (e != a)

min(left+1,
    above+1,
    leftAbove + substCost)

min(3, 5, 4)

		f	a	c	e
	0	1	2	3	4
a	1	1	1	2	3
p	2				
e	3				

Levenshtein Distance - Algorithm

And so on...

The answer is in the lower-right cell of the table:

		f	a	c	e
	0	1	2	3	4
a	1	1	1	2	3
p	2	2	2	2	3
e	3	3	3	3	2