Lecture Notes
Chapter #6
Arrays

1. Array

- solves the problem of storing a large number of values and manipulating them
- is a data structure designed to store a fixed-size sequential collection of elements of the same type, i.e., it is a collection of variables of the same type

2. Array Declarations

- creates a storage location for a Reference to an Array, i.e., creating a Reference Variable for an Array

double[ ] temperature; -- preferred notation
double temperature[ ]; -- inherited from the C programming language

3. Array Creation

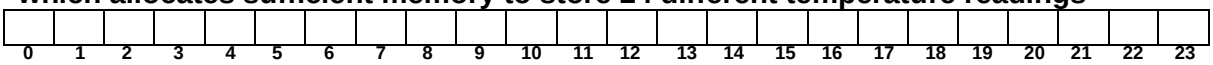
- Specify the Array Size, i.e., Determine the Array Length
- Allocate Memory for the Array
  &
- Assign a Reference to that Memory Location

temperature = new double[24];

Allocating Memory for an Array of doubles

Assigning a Reference to that Memory Location

which allocates sufficient memory to store 24 different temperature readings



4. Creating a Reference Variable, Allocating Memory & Assigning a Reference to that Memory Location

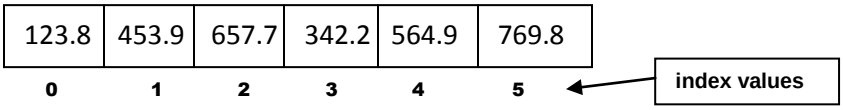
double[ ] temperature = new double[24];

5. Assigning & Using Values Stored in an Array

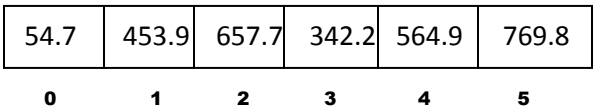
The statement

double[ ] temperature = new double[6];

creates an array



where each cell can be referenced by its index, e.g., temperature[0] = 54.7;
which stores the value 54.7 in cell 0



and
double x = temperature[0];
which retrieves the value 54.7 from cell 0 and places it in the variable x.

6. Array Size

- **is <u>determined when the array is created</u>, i.e., when memory is allocated**
- **size of an existing array, e.g., temperature, can be determined by**
  temperature.length
  which for the above example, returns the value 6
- **once the array is allocated, <u>the length cannot be modified</u>**

7. Array Indexed Variables

temperature[0] = temperature[0] + 5.9;
temperature[0] ← 54.7 + 5.9
60.6

Incrementing variable values

8. Array Initialization

double[ ] temperature = {54.7, 453.9, 657.7, 342.2, 564.9, 769.8};

9. Processing Arrays

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

Initializing an array – all variable values set to zero

```
for( i=0; i < temperature.length; i++)
{
  temperature[i] = Math.random()*100;
}
```

Initializing an array –variable values set to random numbers such that 0<= temperature < 100

```
for( i=0; i < temperature.length; i++)
  System.out.println(temperature[i]);
```

Printing all the values in an array

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

Compute the sum of the values of all variables in the array

```
double max = temperature[0];
double min = temperature[0];
for( i=0; i < temperature.length; i++)
{
  if( temperature[i] > max) max = temperature[i];
  if( temperature[i] < min)  min = temperature[i];
}
```

Compute the maximum and minimum values of all the variables in the array

---

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

Compute the smallest index of the, possibly multiple, maximum value of the array

---

```
double temp = temperature[0];
for( i=0; i < temperature.length; i++)
{
  temperature[i - 1] = temperature[i];
}
```

Shifting the variable values from the left to the right

10. For-Each Loops

```
for( <data-type> element:  temperature)
  System.out.println(element);
```

element must be the same type as the elements in temperature

For-Each Loops cannot be used to traverse the array in a different order nor for modifying the values of the array

11. Copying Arrays

Remember that

double[ ] temperature

creates a Reference Variable, i.e., creates storage space for a reference to an array, but does not allocate storage space for an array.

The statement

double[ ] temperature1 = new double[24];

creates a reference variable for an array, allocates memory for an array& assigns the reference to that array.

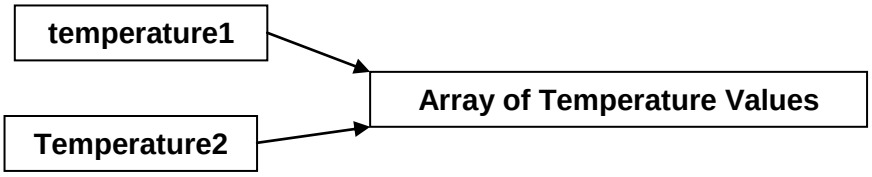
The reference variable temperature1 can be visualized as either a

- handle for the array or
- a pointer to the array.

Thus the statements

```
double[ ] temperature2;
temperature2 = temperature1;
```

creates a new reference variable temperature2 and making it refer to the same array as the reference variable temperature1.

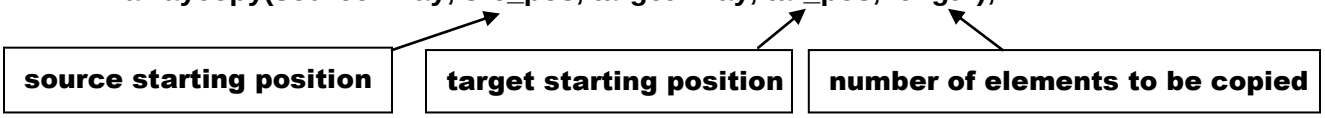


a. Copying Arrays Using a Loop Statement

```
double[ ] temperature1 = {54.7, 453.9,  657.7,  342.2,  564.9,  769.8};

double[ ] temperature2 = new double[temperature1.length];

for( i=0; i < temperature1.length; i++) temperature2[ i ] = temperature1[ i ];
```

b. Copying an Array using the Static arraycopy Method

java.lang.System contains the method arraycopy
arraycopy violates the java naming convention!
syntax
arraycopy(sourceArray, src_pos, targetArray, tar_pos, length);




```
double[ ] temperature1 = {54.7, 453.9,  657.7,  342.2,  564.9,  769.8};
double[ ] temperature2 = new double[temperature1.length];
System.arraycopy(temperature1, 0, temperature2, 0, temperature1.length);
```

c. Copying an Array using the Clone Method (to be discussed in Chapter 10)

12. Passing Arrays to Methods

```
public static void printArray( int [ ] array)
{
  for( int i = 0; i < array.length; i++ )
    System.out.print( array [i] + "  ");
}

printArray( new int [ ] { 3, 1, 2, 6, 2 });
```

Definition of printArray method

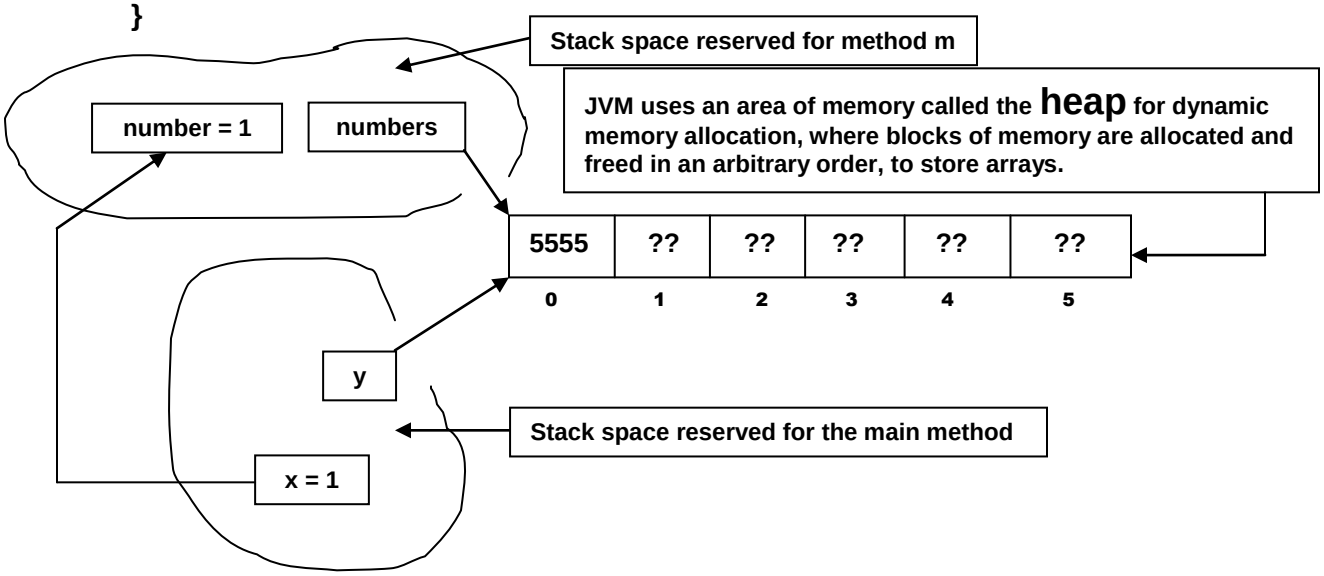
Invocation of printArray method

Anonymous array, i.e., there is no explicit reference variable holding the array; hence the array does not exist outside of the parameter list of the printArray method

Java uses pass-by-value to pass arguments to a method

For an argument of a primitive type, the arguments value is passed.
For an argument of an array type, the value of the argument is a reference to an array; the value of the reference variable is passed. The effect is that arrays are passed by reference, i.e., the method has access to the values stored in the array.

```
public class Test
{
  public static void main(String [ ] args)
  {
    int x = 1;
    int [ ] y = new int [10];
    m(x, y);
    System.out.println("x is " + x);                    // x is 1
    System.out.println("y[0]  is " + y[0]);             // y[0] is 5555
  }

  public static void m(int number, int [ ] numbers)
  {
    number = 1001;
    numbers[0] = 5555;
  }

}
```

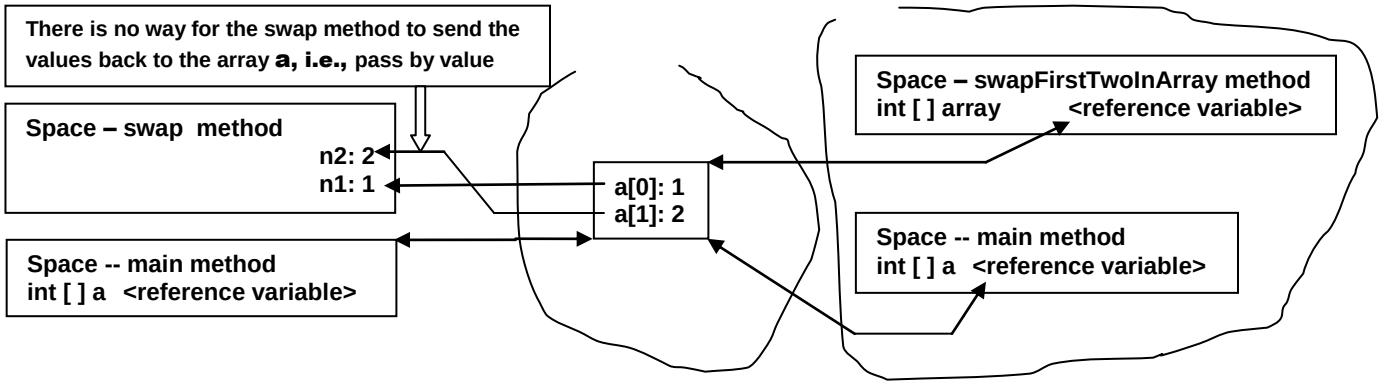


13. Passing Array Elements

```
public static void swap(int n1, n2)
{
  int temp = n1;
  n1 = n2;
  n2 = temp;
}

public static void swapFirstTwoInArray(int [ ] array)
{
  int temp = array[0];
  array[0] = array[1];
  array[1] = temp;
}
```

Invocation Statements

```
int [ ] a = {1, 2};
swap( a[0], a[1]);      ➔ swap( 1, 2 ); thus after swap a == {1, 2}
swapFirstTwoInArray(a);  ➔ after swap a == {2, 1}
```



14. Returning an Array from a Method

```
public static int [ ] reverse(int [ ] list)
{
  int [ ] result = new int [ list.length ];
  for( int i = 0,  j = result.length – 1;  i < list.length; i++, j - - )
        result [ j ] = list [ i ];
return result;
}

int [ ] list1 = {1, 2, 3, 4, 5, 6};
int [ ] list2 = reverse(list1);
                ➔
list2 == {6, 5, 4, 3, 2, 1}
```

15. Counting Letter Occurrences in an Array

Listing 6.4

Use the methods

```
public static char getRandomCharacter(char ch1, char ch2)
{
  return (char) (ch1 + Math.random( ) * (ch2 ch1 + 1));
}
```

```
public static char getRandomLowerCaseLetter( )
{
  return = getRandomCharacter('a', 'z');
}
```

to build the array chars **(see Liang pages 193-194 for details)**

Use the method

```
public static int [ ] countLetters(char [ ] chars)
{
  int [ ] counts = new int[26];
  for ( int i = 0;  i < chars.length;  i++ )
            counts[ chars[ i ] – 'a' ]++;
  return counts;
}
```

to record the count of each lower case letter in an array

16. Variable-Length Argument Lists

- are used to pass a variable number of arguments to a method
- specify a variable-length argument in the method declaration, by stating a data type followed by an ellipsis, i.e., "…", followed by a variable name.
- a parameter list can contain only one variable-length argument and it must be placed at the end of the parameter list.

```
public static void printMinAndMax(double ... numbers)
{
  if ( numbers.length == 0)
  {
    return;
  }
  double max = numbers[0];
  double min = numbers[0];
  for ( int i = 0;  i < numbers.length;  i++ )
    if ( numbers[ i ]  > result )
         max = numbers[ i ];
    else
         min = numbers[ i ];
 System.out.println( "Maximum:   "  + max );
 System.out.println( "Minimum:   "  + min );
}
```

Invocation of a Variable-Length Method

```
printMinAndMax( ); // produces no output

printMinAndMax( 34, 3.2, 9, 15.1, 47, 106, 2.9);     // produces
                                                          Maximum:   106.0
                                                          Minimum:   2.9
printMinAndMax(new double [ ] { 1, 54, -54 });       // produces
                                                          Maximum:   54.0
                                                          Minimum:   -54.0
```

17. Linear Search (of an Array)

Searches an array by comparing the value of a search item with each element in the array one-by-one; e.g., for the array a, below, the search for the value 564.9 would search, in order, cells 0, 1, 2, 3, and then 4 after which the search would terminate.

a

123.8	453.9	657.7	342.2	564.9	769.8
0	1	2	3	4	5

A linear search method can be written is as follows:

```
public class linearSearch( int [ ] list, int key )      // key is the search item
{
  for ( int = 0; i < list.length; i++ )
    if (key == list[ i ])
    {
      return i;
    }
  return -1;
}
```

It returns the index of the desired item as specified in the parameter key if such an item is found in the list, otherwise it returns -1 to signal failure to find such an item.

The execution time of a linear search increases linearly as n increases, hence it is said to be of the order n, i.e., O(n). On average it takes n/2 tries to find the item if it is in the array and n tries if it is not in the array. The linear search algorithm is usually avoided for searches in arrays with large n values.

18. Binary Search (of an Array)

In order to use this algorithm, the array must be sorted.

Assume that it has been sorted in an ascending order, e.g., such as a telephone book. Think of how you search a phonebook; if you are searching for a last name that begins with the letter 'K', you generally open the book in the middle and determine whether the letter 'K' falls in the first half or the second half of the book. In some areas, it will fall in the first and in others it will fall in the second. In either case, you then ignore, i.e., "throw away" the other half of the phonebook as being irrelevant to the current search. You then repeat the process with the relevant section of the phonebook until you locate the desired name or determine that no such person is listed in that phonebook. This is a binary search.

In the first pass, you only need to search ½ of the original list; in the second pass you only search ½ of ½ of the original list; etc., etc., … .

Assume n is a power of 2, i.e., n == 2^m for some m. After the first pass there n/2 elements left to search, after the second pass there are (n/2)/2 elements left to search and after the k^{th} search there are $n/2^k$ elements to search.

When n == $\log_2$ n, only one more element is left in the array and only one more search is necessary to determine whether the desired item is in the array. Hence, in the worst case, binary search requires at most $\log_2$ n + 1 comparisons.

Remember that the linear search on an array of length n required n comparisons in the worst case.

Worst case search on a list of 1024 elements

- **Linear Search ➔ 1023 comparisons**
- **Binary Search ➔ 11 comparisons**

9300% improvement

Defining a Binary Search Algorithm

Let low denote the first index and high denote the last index of the array segment that is currently being searched.

Initially low = 0 and high = list.length-1;

Let mid denote the index of the middle element of the array segment that is currently being searched.

Hence mid = (low + high)/2;

remember that the indexes are all integers so that the computation of mid uses integer division, e,g, mid = (15 + 42)/2 yields 28.

The binary search algorithm given below, returns the

- **index of the desired item, if such an item is contained in the array**
- **the value -1*(insertion point -1), if the item is not in the array**

where the insertion point is the index of the point at which the item should be inserted into the array to maintain the sorted order of the array

```
public class BinarySearch
{
  public static int binarySearch(int [ ] list, int key)
  {
    int low = 0;
    int high = list.length - 1;
    while ( high >= low)
    {
      int mid = (low + high)/2;
      if ( key < list[mid]) high = mid -1;
     else if ( key == list[mid])        return mid;
     else  low = mid + 1;
    }
    Return – low -1; //  in this case we have  high < low
  }
}
```

Homework: page 198 trace the algorithm as suggested in the text!!

19. Selection Sort (of an Array)

Locate largest element in the array, swap that element with the element in the last place in the array. Locate second largest element in the array, swap that element with the element in the next to last place in the array. Continue this process until the array is sorted. For example,

2	9	5	4	8	1	6
2	6	5	4	8	1	9
2	6	5	4	1	8	9
2	1	5	4	6	8	9
2	1	4	5	6	8	9
2	1	4	5	6	8	9
2	1	4	5	6	8	9
1	2	4	5	6	8	9

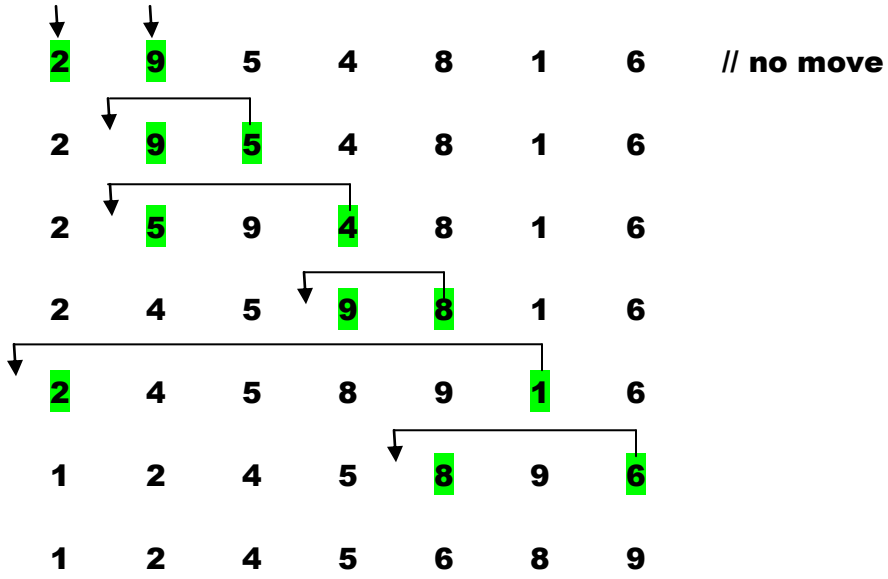
```
public class SelectionSort
{
  public static void selectionSort(double [ ] list)
  {
    for ( int i = list.length – 1; i >= 1; i-- )
    {
      double currentMax = list[0];
      int currentMaxIndex = 0;

      for ( int j = 1; j <= i; j-- )
      {
        if ( currentMax < list[ j ])
        {
          currentMax = list[ j ];
          currentMaxIndex = j;
        }
      }
      if ( currentMax != i)
      {
        list[ currentMaxindex] = list[ i ];
        list[ i ] = currentMax;
      }

    }
  }
}
```

Homework: page 200 trace the algorithm as suggested

20. Insertion Sort (of an Array)

Moving on cell at a time across the array, place the selected value in its correct location, shifting the values of all the other cells to make the necessary room, e.g., forming a military line based on the decreasing/increasing height of the solders

Example




```
public class Insertionsort
{
  public static void insertionSort(double [ ] list)
  {
    for ( int i = 1; i < list.length; i++ )
    {
      double currentElement = list[ i ];
      int k;
      for ( k = i -1; k >= 0 && list[ k ] > currentElement; k --)
        list[ k + 1 ] = list[ k ];
      list[ k + 1 ] = currentElement;
    }
  }
}
```

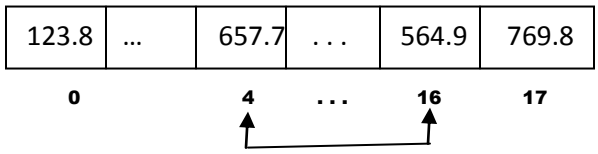
Homework: page 202 trace the algorithm as suggested

21. Arrays Class

java.util.Arrays

- **contains various static methods dealing with arrays**
- **overloaded for the primitive types**
- **java.util.Arrays.sort(numbers); // sorts the array numbers**
- **java.util.Arrays.sort(numbers, 4, 17); // sorts the portion of the array between numbers[4] and numbers[16], inclusive, i.e., [4 , 17).**

numbers



- **java.util.Arrays.binarySearch(<array_name, search_target>);**
  e.g., java.util.Arrays.binarySearch(numbers, 657.7);

- **java.util.Arrays.equals(list1, list2);**
  e.g., if list1, list2 and list3 are defined as
  int [ ] list1 = { 1, 2, 3, 5 };
  int [ ] list2 = { 1, 2, 3, 5 };
  int [ ] list3 = { 1, 2, 3, 4 };
  then
  java.util.Arrays.equals(list1, list2) returns TRUE
  and
  java.util.Arrays.equals(list1, list3) returns FALSE

- **java.util.Arrays.fill(list1, 0) → list1 contains { 0, 0, 0, 0 }**
  and
- **java.util.Arrays.fill(list2, 1, 2, 0) → list2 contains { 1, 0, 0, 5 }**

22. Two-Dimensional Arrays

int [ ] [ ] matrix = new int [5] [10]; // produces the two-dimensional array

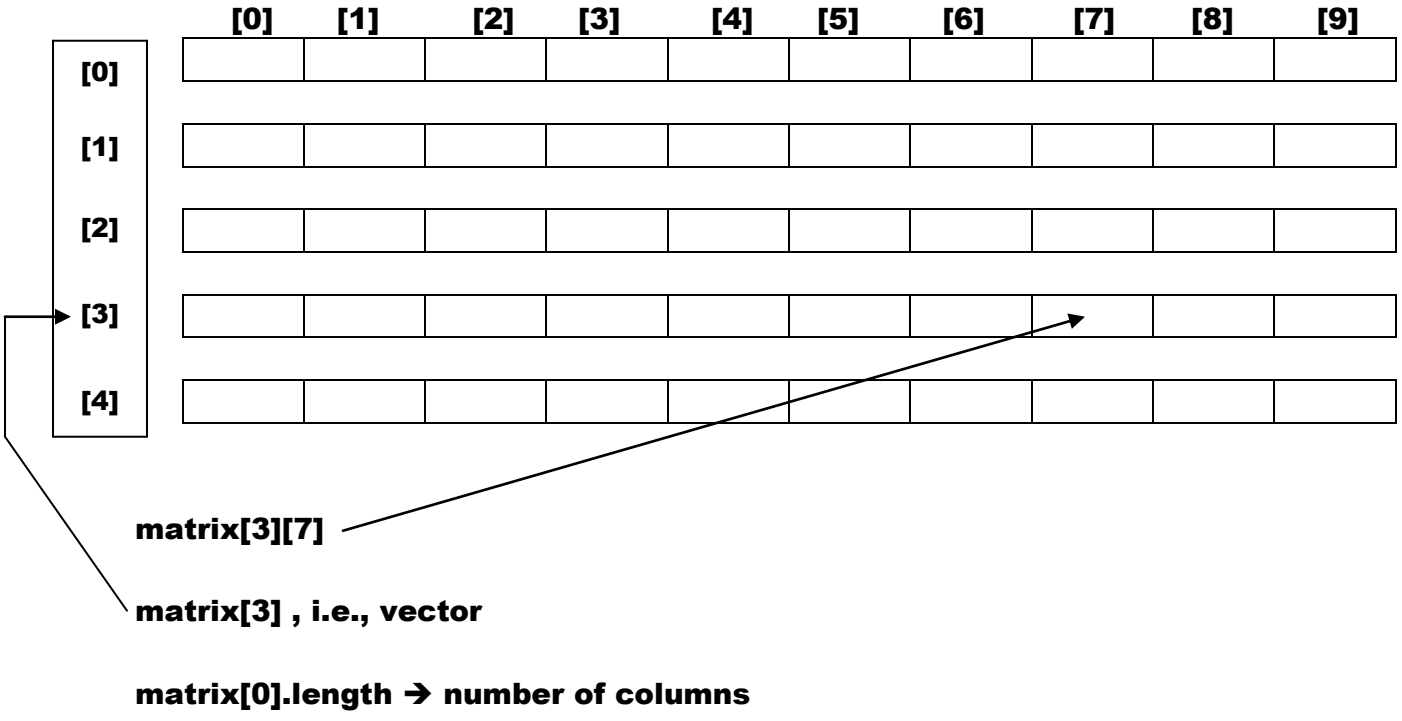
	[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
[0]										
[1]										
[2]						29				
[3]										
[4]										

where matrix[2][5] = 29 places the value 29 in the cell at row 2, column 5

java.util.Arrays.fill(matrix[0], 1); // produces

	[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
[0]	1	1	1	1	1	1	1	1	1	1
[1]										
[2]						29				
[3]										
[4]										

A two-dimensional array is, in actual fact, an array of arrays, i.e.,



matrix[0].length → number of columns

23. Ragged Arrays

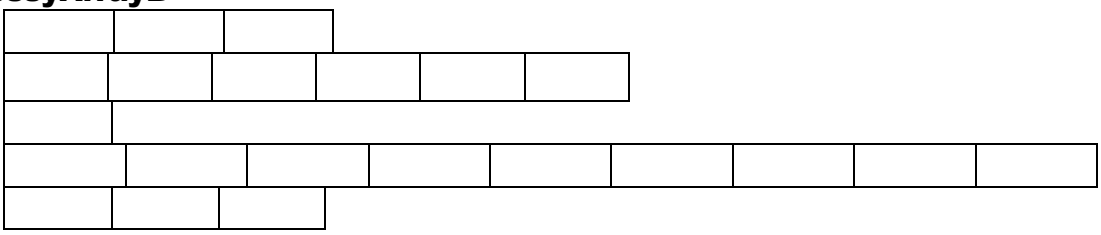
```
int [ ] [ ] messyArray = {
                          {1, 2, 3},
                          (4, 5, 6, 7, 8, 9 },
                          { 0 },
                          { 7, 6, 35, 29, 190, -19, 57, 209, 41 },
                          { 987, 8796, 1982 }
                         };
```

produces

1	2	3						
4	5	6	7	8	9			
0								
7	6	35	29	190	-19	57	209	41
987	8796	1982						

```
int [ ] [ ] messyArrayB = new int [5][ ];
messyArrayB[0] = new int[3];
messyArrayB[1] = new int[6];
messyArrayB[2] = new int[1];
messyArrayB[3] = new int[9];
messyArrayB[4] = new int[3];
```

produces
messyArrayB



24. Processing Two-Dimensional Arrays

```
int [ ] [ ] matrix = new int [5][10];
int total = 0;
```

matrix.length == 5

```
for ( int row = 0; row < matrix.length; row++ )
{
  for ( column = 0; column < matrix[row].length; column++ )
  {
    matrix[row][column] = (int)(Math.random( ) * 100);
  }
}
```

matrix[row].length == 10
i.e., matrix[0].length == 10

```
for ( int row = 0; row < matrix.length; row++ )
{
  for ( column = 0; column < matrix[row].length; column++ )
  {
    System.out.print(matrix[row][column]  + "  ");
  }
  System.out.println( );
}
```

```
for ( int row = 0; row < matrix.length; row++ )
{
  for ( column = 0; column < matrix[row].length; column++ )
  {
    total += matrix[row][column];
  }
}
```

```
for ( int column = 0; column < matrix[0].length; column++ )
{
  int total = 0;
  for ( row = 0; row < matrix.length; row++ )
        total += matrix[row][column];
  System.out.println("Column: " + column + "Total: " + total );
}
```

```
  for ( row = 0; row < matrix.length; row++ )
{
  int total = 0;
  for ( int column = 0; column < matrix[0].length; column++ )
        total += matrix[row][column];
  System.out.println("Row: " + row + "Total: " + total );
}
```

---

25. Multidimensional Arrays

a. **Two-Dimensional Arrays ➔ Tables, Matrices**
   Consists of an Array of One-Dimensional Arrays, i.e., Vectors

b. **Three-Dimensional Arrays ➔ Cubes, e.g., Rubic's Cube**
   Consists of
   i. **an Array of Two-Dimensional Arrays, i.e., Tables or Matrices, or**
   ii. **an Array of an Array of One-Dimensional Arrays, i.e., Vectors**

c. **Four-Dimensional Arrays, e.g.,**
   temperature(hours[24], days[7], weeks[52] years[500])
   defined by
   double [ ] [ ] [ ] [ ] temperature = new double [24] [7] [52] [500];
   Consists of …
   i. **an Array of Three-Dimensional Arrays, i.e., Tables or Matrices, or**
   ii. **an Array of an Array of an Array of One-Dimensional Arrays, i.e., Vectors**

   The statement
   temperature[11][2][4][5] = 97.4;
   specifies that the temperature at recorded for the hour 11, day 2, week 4, year 5 was 97.4

For a general four-dimensional array, e.g., double votive[10][10][10][10];
the meaning of votive[0][0][0][0] must be established by the <u>context</u> of the encompassing program.

26. Programs to Study, Trace, & Understand

(programs that you will be expected to understand on the midterm exam)

- **Listing 6.11**
- **Listing 6.12**
- **Listing 6.13**
- **Listing 6.14**

27. Potential Midterm Examination Questions

- **Any Material Covered in Liang textbook Chapters 1 through 6 inclusively**
- **Review Questions (any)**
- **Program Listings in Liang (any)**
- **Projects Assigned and Collected**
- **Lectures 1 thru 6 (see Lecture Notes)**

28. How to Study

- **Using the resources in #27 above, make an exhaustive set of notes of those points that you might be asked questions in the Exam, but which you think that you might not be able to recall**
- **Reduce the notes created above to a set of 3x5 cards, listing only those points that you now think that you might not be able to recall**
- **Repeat this process until you only need one 3x5 card**
- **Reduce this 3x5 card to a 2x3 card; bring the card with you to look at 10 minutes before the exam starts; put the card away and take the exam!**