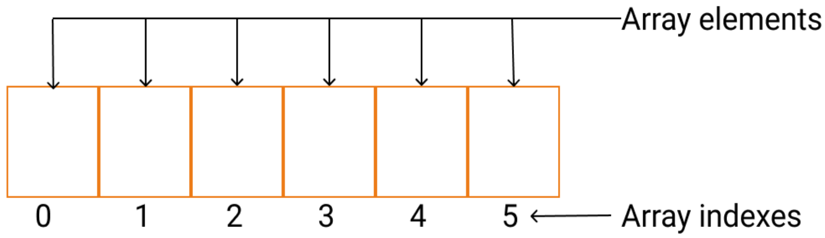
Array

- An Array is a Linear data structure
- It is a collection of data items having similar data types stored in contiguous memory locations.
- By knowing the address of the first item we can easily access all items/elements of an array.
- Arrays and its representation is given below.



- Array Dsicription:
  - **Array Index:** The location of an element in an array has an index, which identifies the element. Array index starts from 0.
  - **Array element:** Items stored in an array is called an element. The elements can be accessed via its index.
  - **Array Length:** The length of an array is defined based on the number of elements an array can store. In the above example, array length is 6 which means that it can store 6 elements.
- When an array of size and type is declared, the compiler allocates enough memory to hold all elements of data.
- E.g. an array face [10] will have 10 elements with index starting from 0 to 9 and the memory allocated contiguously will be 20 bytes (integer = 2 bytes).
- The compiler knows the address of the first byte of the array only. Also, the address of the first byte is considered as the memory address for the whole array.

Types of Arrays

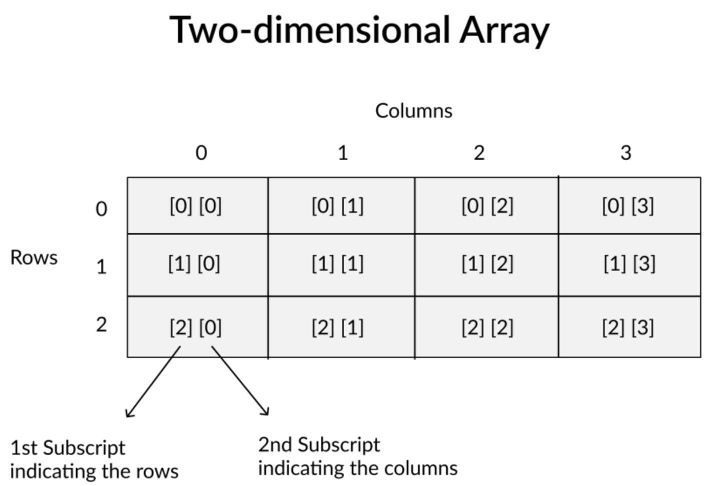
The various types of arrays are as follows.

- One dimensional array
- Multi-dimensional array

- **One-Dimensional Array**
  - A one-dimensional array is also called a single dimensional array
  - where the elements will be accessed in sequential order.

- This type of array will be accessed by the subscript of either a column or row index.

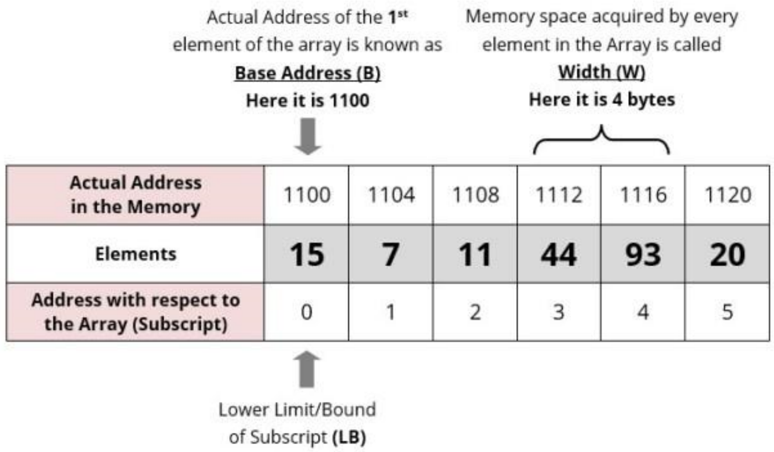
- **Multi-Dimensional Array**
    - When the number of dimensions specified is more than one, then it is called as a multi-dimensional array.
    - Multidimensional arrays include 2D arrays and 3D arrays.



- **E.g. A two-dimensional array**
    - Accessed with subscript of row and column index
    - For traversal the value of the rows and columns will be considered
    - E.g. **face [3] [4],** the first index specifies the number of rows and the second index specifies the number of columns and the array can hold 12 elements (3 * 4)

- **A three-dimensional array**
    - The array **face [5] [10] [15]** can hold 750 elements (5 * 10 * 15).

<u>Address Calculation in single (one) Dimension Array:</u>



- Address of an element A[I] is calculated using the following formula:
- 1100 + (1—0) *4
- 1100 + (4-0) * 4
    - **Address of A [I] = B + W * (I – LB)**
    - Where,
      B = Base address
      W = Storage Size of one element stored in the array (in byte)
      I = Subscript of element whose address is to be found
      LB = Lower limit / Lower Bound of subscript, if not specified assume 0 (zero)

    - **Example:**

Base address of an array **B[1300…..1900]** as **1020 and size of each element** is **2 bytes in the memory. Find the address of B[1700]**

Solution:

Sol : B = 1020, LB = 1300, W = 2, I = 1700

Address of A [I] = B + W * (I – LB)
= 1020 + 2 * (1700 – 1300)
= 1020 + 2 * 400
= 1020 + 800
= 1820

Why does Array Indexing start with 0?

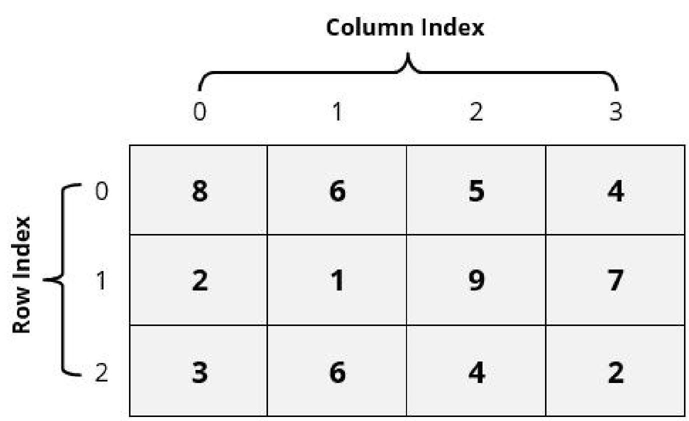
- Here **a** itself is a pointer which contains the memory location of the first element of the array

- first element can be accessed with **a[0]**
    - internally decoded by the compiler as ***(a + 0)**.
- second element can be accessed by **a[1]** or ***(a + 1)**.
- As **a** contains the address of the first element = Base Address
- and index describes the offset from the first element, i.e. the distance from the first element.

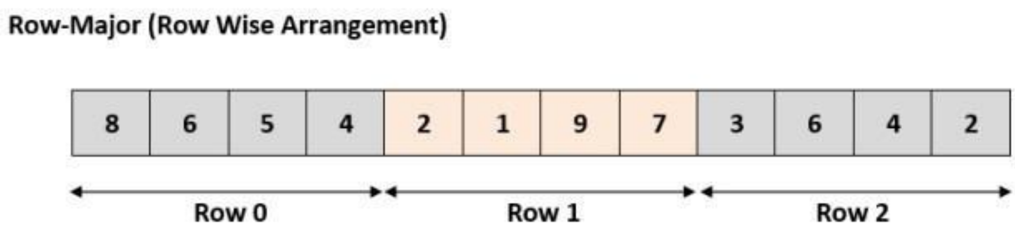
    - If array indexing starts at 1 instead of 0
    - the first element can be accessed by **a[1]**
        - which is internally decoded as ***(a + 1 – 1)**.
- Thus we have to perform one extra operation i.e. subtraction by 1.
- This extra operation will greatly decrease the performance when the program is big.
- Thus to avoid this extra operation and improve the performance, array indexing starts at 0 and not at 1.

Address Calculation in Double (Two) Dimensional Array:

- While storing the elements of a 2-D array in memory, these are allocated contiguous memory locations.
- Therefore, a 2-D array must be linearized so as to enable their storage.
- There are two alternatives to achieve linearization:
    - Row-Major
    - Column-Major.



Two-Dimensional Array



0	1	2	3	4	5	6	7	8	9	10	11

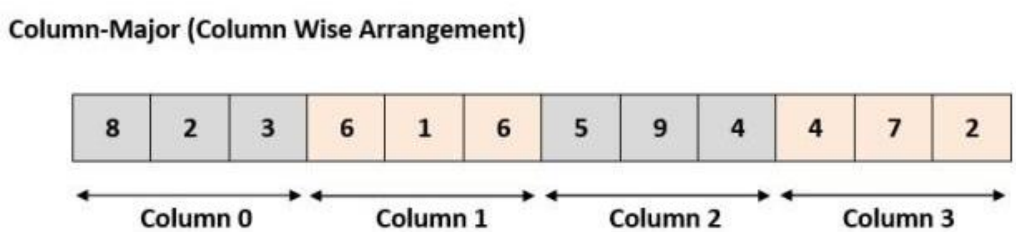
- Address of an element A[I][J] = = B + W * [N * (I – Lr) + (J – Lc)] for thr array declared as A[M][N]

Where
B = Base address
I = Row subscript of element whose address is to be found
J = Column subscript of element whose address is to be found
W = Storage Size of one element stored in the array (in byte)
Lr = Lower limit of row/start row index of matrix, if not given assume 0 (zero)
Lc = Lower limit of column/start column index of matrix, if not given assume 0 (zero)
M = Number of row of the given matrix
N = Number of column of the given matrix

Example : for the given A[4][4] with A[0..3][0..3]

  - Address of A[1][1] = B + W * [4 * (1-0) + (1-0)]
    = B + W *[5]

Column Oriented storage :



- **Address of A[I][J] = B + W * [M*(J – Lc) + (I – Lr)]**

Where

B = Base address

I = Row subscript of element whose address is to be found

J = Column subscript of element whose address is to be found

W = Storage Size of one element stored in the array (in byte)

Lr = Lower limit of row/start row index of matrix, if not given assume 0 (zero)

Lc = Lower limit of column/start column index of matrix, if not given assume 0 (zero)

M = Number of row of the given matrix

N = Number of column of the given matrix

- **Important Note :**
    - Usually number of rows and columns of a matrix are given (like A[20][30] or A[40][60]) but if it is given as **A[Lr- – – – – Ur, Lc- – – – – Uc]**. In this case number of rows and columns are calculated using the following methods:
        - Number of rows (**M**) will be calculated as = **(Ur – Lr) + 1**

          Number of columns (**N**) will be calculated as = **(Uc – Lc) + 1**
        - And rest of the process will remain same as per requirement (Row Major Wise or Column Major Wise).

Examples:

Q 1. An array X [-15……….10, 15……………40] requires **one byte of storage**. If beginning location is 1500 determine the location of X [15][20].

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Solution:
As you see here the number of rows and columns are not given in the question. So they are calculated as:

Number or rows say **M = (Ur – Lr) + 1** = [10 – (- 15)] +1 = 26
Number or columns say **N = (Uc – Lc) + 1** = [40 – 15)] +1 = 26

(i) Row Major Wise Calculation of above equation

The given values are: B = 1500, W = 1 byte, I = 15, J = 20, Lr = -15, Lc = 15, N = 26

Address of A [I][J] = B + W * [N * (I – Lr) + (J – Lc)]

= 1500 + 1* [26 * (15 – (-15))) + (20 – 15)]
= 1500 + 1 * [26 * 30 + 5]
= 1500 + 1 * [780 + 5]
= 1500 + 785
= 2285 **[Ans]**

int A[15][20];

What would be the address of A[5][5] if storage is Row major or Column major? (Given the base address = 100)

100 + 20*5 + 5 = 310
100 + 15*5 +5 = 260

A[4][4]

100 + 2(80+4) = 268
100 + 2(60+4) = 228

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= 1500 + 1* [26 * (15 – (-15))) + (20 – 15)]
= 1500 + 1 * [26 * 30 + 5]
= 1500 + 1 * [780 + 5]
= 1500 + 785
= 2285 **[Ans]**

(ii) Column Major Wise Calculation of above equation

The given values are: B = 1500, W = 1 byte, I = 15, J = 20, Lr = -15, Lc = 15, M = 26

Address of A [I][J] = B + W * [(I – Lr) + M * (J – Lc)]

= 1500 + 1 * [(15 – (-15)) + 26 * (20 – 15)]
= 1500 + 1 * [30 + 26 * 5]
= 1500 + 1 * [160]
= 1660 **[Ans]**

Total memory allocated to an Array = Number of elements * size of one element

Single Dimension:

Total memory allocated for an Integer Array of N elements
= Number of elements * size of one element
= N * 4 bytes
= 10 * 4 bytes = **40 Bytes**, where N = 10
= 500 * 4 bytes = **2000 Bytes**, where N = 500

Total memory allocated for an character Array of N elements
= Number of elements * size of one element
= N * 1 Byte
= 10 * 1 Byte = **10 Bytes**, where N = 10
= 500 * 1 Byte = **500 Bytes**, where N=500

Two Dimensions :

Total memory allocated for 2D Array
= Number of elements * size of one element
= Number of Rows * Number of Columns * Size of one element

Total memory allocated for an Integer Array of size M X N
= Number of elements * size of one element
=M Rows* N Columns * 4 Bytes
= 10*10 * 4 bytes = **400 Bytes**, where M =N = 10
= 500*5 *4 bytes= **10000 Bytes**, where M=500 and N= 5

Total memory allocated for a character Array of N elements
= Number of elements * size of one element
= M Rows* N Columns * 1 Byte
= 10*10 * 1 Byte = **100 Bytes**, where N = 10
= 500*5 * 1 Byte = **2500 Bytes**, where M=500 and N= 5

Example 2:

Each element of an array arr[15][20] requires ‘W’ bytes of storage. If the address of arr[6][8] is 4440 and the base address at arr[1][1] is 4000, find the width ‘W’ of each cell in the array arr[][] when the array is stored as Column Major Wise.

Solution: Example 2:

Each element of an array **arr[15][20] requires** 'W' bytes of storage. If the **address of arr[6][8] is 4440** and the **base address at arr[1][1]** is 4000, find the width 'W' of each cell in the array arr[][] when the array is stored as **Column Major Wise**.

Given :

B = Base address = 4000

I = Row subscript of element whose address is to be found = 6

J = Column subscript of element whose address is to be found = 8

W = Storage Size of one element stored in the array (in byte) = NOT Given

Lr = Lower limit of row/start row index of matrix = 1

Lc = Lower limit of column/start column index of matrix = 1

M(or R) = Number of row of the given matrix = 15

N (or C) = Number of column of the given matrix = 20

Solution: Example 2:

Each element of an array **arr[15][20] requires** 'W' bytes of storage. If the **address of arr[6][8] is 4440** and the **base address at arr[1][1]** is 4000, find the width 'W' of each cell in the array arr[][] when the array is stored as **Column Major Wise**.

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I = Row subscript of element whose address is to be found = 6

J = Column subscript of element whose address is to be found = 8

W = Storage Size of one element stored in the array (in byte) = NOT Given

Lr = Lower limit of row/start row index of matrix = 1

Lc = Lower limit of column/start column index of matrix = 1

M(or R) = Number of row of the given matrix = 15

N (or C) = Number of column of the given matrix = 20

Address of $[I, J]^{th}$ element in column-major

$= B + W[R(J – L_c) + (I – L_r)]$

$\Rightarrow 4440 = 4000 + W[15(8 – 1) + (6 – 1)]$

$\Rightarrow 4440 = 4000 + W[15(7) + 5]$

$\Rightarrow 4440 = 4000 + W[105 + 5]$

$\Rightarrow 4440 = 4000 + W[110]$

$\Rightarrow W[110] = 440$

$\Rightarrow W = 4.$

Example 3:

A matrix ARR[-4…6, 3…8] is stored in the memory with each element requiring 4 bytes of storage. If the base address is 1430, find the address of ARR[3][6] when the matrix is stored in Row Major Wise.

Given :

B = Base address = 1430

I = Row subscript of element whose address is to be found = 3

J = Column subscript of element whose address is to be found = 6

W = Storage Size of one element stored in the array (in byte) = 4

Lr = Lower limit of row/start row index of matrix = -4

Lc = Lower limit of column/start column index of matrix = 3

M(or R) = Number of row of the given matrix = 6 – (-4) + 1 = 11

N (or C) = Number of column of the given matrix = 8 – 3 +1 = 6

Example 3:

A matrix ARR[-4…6, 3…8] is stored in the memory with each element requiring 4 bytes of storage. If the base address is 1430, find the address of ARR[3][6] when the matrix is stored in Row Major Wise.

Given :

B = Base address = 1430

I = Row subscript of element whose address is to be found = 3

J = Column subscript of element whose address is to be found = 6

W = Storage Size of one element stored in the array (in byte) = 4

Lr = Lower limit of row/start row index of matrix = -4

Lc = Lower limit of column/start column index of matrix = 3

M(or R) = Number of row of the given matrix = 6 – (-4) + 1 = 11

N (or C) = Number of column of the given matrix = 8 – 3 +1 = 6

Address of [I, J]th element in row-major

$= B + W[C(I - L_r) + (J - L_c)]$

$\Rightarrow$ Address of ARR[3][6] = 1430 + 4[6(3 – (-4)) + (6 – 3)]

$\Rightarrow$ Address of ARR[3][6] = 1430 + 4[6(3 + 4) + 3]

$\Rightarrow$ Address of ARR[3][6] = 1430 + 4[6(7) + 3]

$\Rightarrow$ Address of ARR[3][6] = 1430 + 4[42 + 3]

$\Rightarrow$ Address of ARR[3][6] = 1430 + 4[45]

$\Rightarrow$ Address of ARR[3][6] = 1430 + 180

$\Rightarrow$ Address of ARR[3][6] = 1610.