

Data Structures and Algorithms (CS 2001)

KALINGA INSTITUTE OF INDUSTRIAL TECHNOLOGY

School of Computer Engineering



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4 Credit

Lecture Note

Chapter Contents



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Sr #	Major and Detailed Coverage Area	Hrs
2	Arrays Arrays, Abstract Data Type, Dynamically Allocated Arrays, Polynomials, Two-dimensional Array, Address Calculation, Matrix Addition and Multiplication, Sparse Matrix, Upper & Lower Triangular Matrix, Tridiagonal Matrix	5

Arrays



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Data Structures are classified as either **Linear** or **Non-Linear**.

- ❑ **Linear data structure:** A linear data structure traverses the data elements sequentially, in which only one data element can directly be reached. Ex: Arrays, Linked Lists
- ❑ **Non-Linear data structure:** Every data item is attached to several other data items in a way that is specific for reflecting relationships. The data items are not arranged in a sequential structure. Ex: Trees, Graphs

Arrays

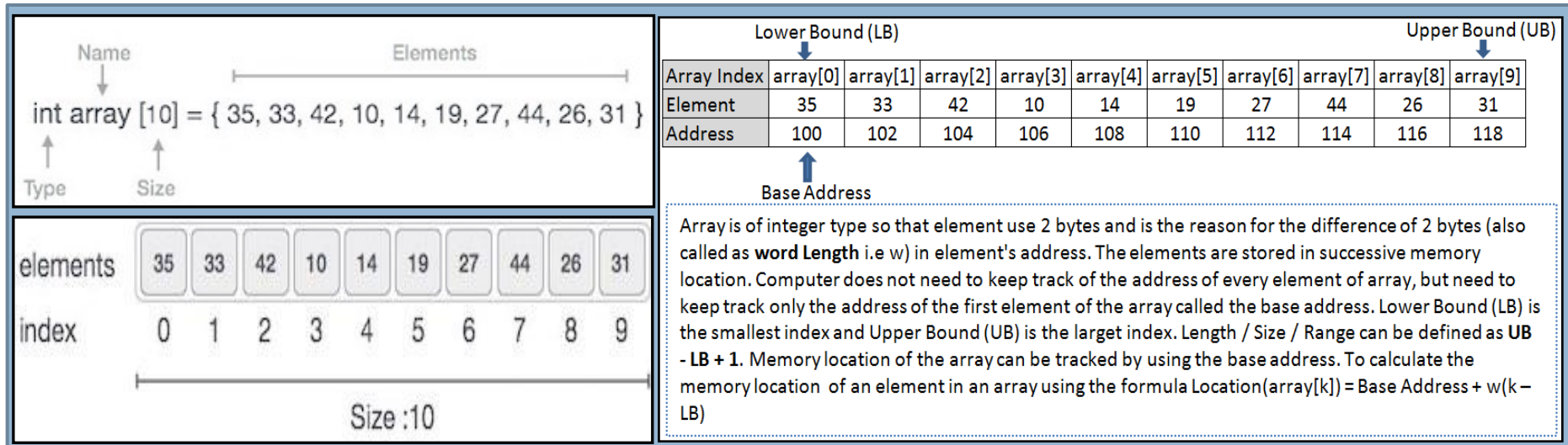
Array is a **container** which can hold fix number of items and these items should be of **same type**. Following are important terms to understand the concepts of Array. Arrays are of one-dimensional or multi-dimensional (i.e. 2 or more than 2)

- ❑ **Element** – Each item stored in an array.
- ❑ **Index** – Each location of an element in an array has a numerical index which is used to identify the element.



One-Dimensional Array

One-Dimensional array is also called as linear array and stores the data in a single row or column.



- ❑ Index starts with 0
- ❑ Array length/size/range is 10 (i.e. $9 - 0 + 1$) which means it can store 10 elements.
- ❑ Each element can be accessed via its index. For example, we can fetch element at index 6 as 27.
- ❑ Address ($array[6]$) = $100 + 2 * (6 - 0) = 112$?



1-D Array Address Calculation

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Address of an element of an array say “A[i]” is calculated using the following formula:

$$\text{Address of A [i]} = \text{BA} + w * (i - \text{LB})$$

Where,

BA = 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

Problem: Given the 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:

The given values are: B = 1020, LB = 1300, W = 2, i = 1700

$$\text{Address of A [i]} = \text{BA} + w * (i - \text{LB})$$

$$= 1020 + 2 * (1700 - 1300)$$

$$= 1020 + 2 * 400$$

$$= 1020 + 800 = 1820$$

Two-Dimensional Array



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C uses the so-called **array-of-arrays** representation to represent a multidimensional array. In this representation, a 2-dimensional array is represented as a one-dimensional array in which each element is itself a one-dimensional array. In layman term, it is the collection of elements placed in rows and columns. For 2-dimensional, 2 types of memory arrangement i.e. **Row-Major arrangement** and **Column-Major arrangement**

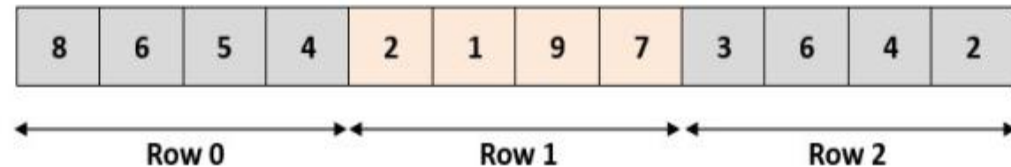
2-D Array

		Column Index			
		0	1	2	3
Row Index	0	8	6	5	4
	1	2	1	9	7
	2	3	6	4	2

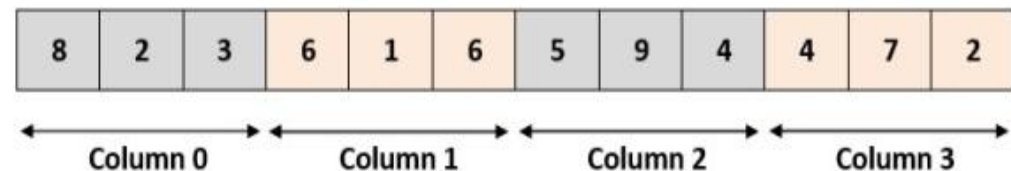
Two-Dimensional Array

Row-Major and Column-Major arrangement

Row-Major (Row Wise Arrangement)



Column-Major (Column Wise Arrangement)



Note : C supports row major order and **Fortran** supports column major order

Row major & Column order Address Calculation



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- ❑ **Row-Major Order:** The address of a location in Row Major System is calculated as:
Address of A [i][j] = $BA + w * [n * (i - Lr) + (j - Lc)]$
- ❑ **Column-Major Order:** The address of a location in Column Major System is calculated as:
Address of A [i][j] = $BA + w * [(i - Lr) + m * (j - Lc)]$

Where:

BA = 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

Row major & Column order Address Calculation cont...



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Important: 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 .

Example:

5	1	8
6	4	7
9	3	2

In figure there is 3x3 array and memory location start from 200 and each element takes 2 address. Calculate element address at Array $[2][1]$ for both row and column major.

Answer: Here $m=n=3$, $i=3$, $j=1$, $w=2$, base address=200.

Row-Major = $BA + w * [n * (i - Lr) + (j - Lc)] = 200 + 2(3(2-0) + (1-0)) = ?$

Column-Major = $BA + w * [(i - Lr) + m * (j - Lc)] = 200 + 2((2-0) + 3*(1-0)) = ?$

Class Work



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

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

$$\text{Number of rows say } m = (U_r - L_r) + 1 = [10 - (-15)] + 1 = 26$$

$$\text{Number of columns say } n = (U_c - L_c) + 1 = [40 - 15] + 1 = 26$$

Column-Major :

The given values are: BA = 1500, w = 1 byte, i = 15, j = 20, Lr = -15, Lc = 15, m = 26

$$\begin{aligned}\text{Address of } A[i][j] &= BA + w * [(i - L_r) + m * (j - L_c)] \\ &= 1500 + 1 * [(15 - (-15)) + 26 * (20 - 15)] \\ &= 1500 + 1 * [30 + 26 * 5] = 1500 + 1 * [160] = 1660\end{aligned}$$

Row-Major:

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

$$\begin{aligned}\text{Address of } A[i][j] &= BA + w * [n * (i - L_r) + (j - L_c)] \\ &= 1500 + 1 * [26 * (15 - (-15)) + (20 - 15)] \\ &= 1500 + 1 * [26 * 30 + 5] = 1500 + 1 * [780 + 5] = 1500 + 785 = 2285\end{aligned}$$

Dynamic Memory Allocation



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The exact size of **array** is **unknown** until the **compile time** i.e. time when a compiler compiles code written in a programming language into a executable form. The size of array you have declared initially can be sometimes **insufficient** and sometimes **more than required**.

What?

The process of allocating memory during program execution is called dynamic memory allocation. It also allows a program to obtain more memory space, while running or to release space when no space is required.

Difference between static and dynamic memory allocation

Sr #	Static Memory Allocation	Dynamic Memory Allocation
1	User requested memory will be allocated at compile time that sometimes insufficient and sometimes more than required.	Memory is allocated while executing the program.
2	Memory size can't be modified while execution.	Memory size can be modified while execution.

Dynamic Memory Allocation Example



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One-Dimensional Array

```
#include <stdio.h>
#include <stdlib.h>
int main()
{
    int n, *list;
    printf("\nEnter the no of elements:");
    scanf("%d", &n);
    if (n < 1)
    {
        printf("Incorrect Value");
        return;
    }
    list = (int *) malloc(n * sizeof(int));
    if (!list)
    {
        printf("Insufficient Memory");
        return;
    }
    /* Allow the users to enter values and display it*/
    /* print the values */
    free(list);
    return 0;
}
```

Two-Dimensional Array

```
#include <stdio.h>
#include <stdlib.h>
int main()
{
    int rows, columns, **list;
    printf("\nEnter the no of rows and columns:");
    scanf("%d%d", &rows, &columns);
    if (rows < 1 || columns < 1)
    {
        printf("Incorrect Value");
        return;
    }
    list = (int **) malloc(rows * sizeof(int *));
    if (!list)
    {
        printf("Insufficient Memory");
        return;
    }
    for (int i=0; i<rows; ++i)
    {
        list[i] = (int *) malloc(columns * sizeof(int));
    }
    if (!list)
    {
        printf("Insufficient Memory");
        return;
    }
    /* Allow the users to enter values and then display it*/
    /* print the values */
    free(list);
    return 0;
}
```



Dynamic Memory Allocation Example cont...

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Find sum of n elements entered by user

```
#include <stdio.h>
#include <stdlib.h>
int main()
{
    int n,i,*ptr,sum=0;
    printf("Enter number of elements: ");
    scanf("%d",&n);
    ptr=(int*)malloc(n*sizeof(int));
    // ptr=(int*)calloc(n, sizeof(int));
    if(ptr==NULL)
    {
        printf("Error! memory not allocated.");
        return;
    }
```

```
    printf("Enter elements of array: ");

    for(i=0;i<n;++i)
    {
        scanf("%d",ptr+i);
        sum+=*(ptr+i);
    }
    printf("Sum=%d",sum);
    free(ptr);
    return 0;
}
```

Pointer to array



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Pointer to 1-D array

```
int i;  
int a[5] = {1, 2, 3, 4, 5};  
int *p = a;  
for (i=0; i<5; i++)  
{  
    printf("%d,", a[i]);  
printf("%d\n", *(p+i));  
}
```

Pointer to 2-D array

```
int i,j;  
int a[3,2] = {{1, 2}, {3, 4}, {1,5}};  
int **p = (int **) a;  
for (i=0; i<3; i++)  
{  
    for (j = 0;j<2;j++)  
    {  
        printf("%d", &a[i][j]);  
printf("%d\n", *((arr +i* 3) + j));  
    }  
}
```

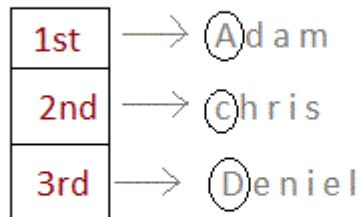
Array of Pointers

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Array of pointers

```
char *name[3]={
    "Adam",
    "chris",
    "Deniel"};
```

Using Pointer



char* name[3]

Only 3 locations for pointers, which will point to the first character of their respective strings.

Array without pointers

```
char name[3][20]= {
    "Adam",
    "chris",
    "Deniel"};
```

Without Pointer

A	d	a	m			
c	h	r	i	s		
D	e	n	i	e	l	

char name[3][20]

extends till 20
memory locations



Pointer to Structure

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```
struct Book
```

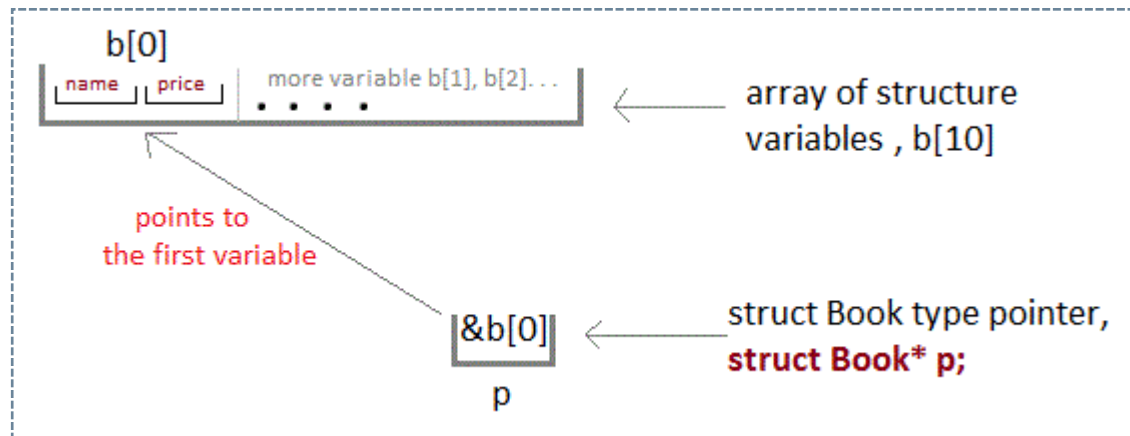
```
{  
  char name[10];  
  int price;  
}
```

```
int main()  
{
```

```
  struct Book a;    //Single structure variable  
  struct Book* ptr; //Pointer of Structure type  
  ptr = &a;
```

```
  ptr->name = "Dan Brown"; //Accessing Structure Members  
  ptr->price = 500;
```

```
  struct Book b[10]; //Array of structure variables  
  struct Book* p;    //Pointer of Structure type  
  p = &b;  
}
```



Array ADT



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An abstract data type (**ADT**) is a mathematical model for data types where a data type is defined by its behavior (semantics) from the **point of view of a user of the data**, specifically in terms of **possible values, possible operations on data of this type**, and **the behavior of these operations**. When considering **Array ADT** we are more concerned with the **operations** that can be performed on array.

Basic Operations

- ❑ **Traversal** – print all the array elements one by one.
- ❑ **Insertion** – add an element at given index.
- ❑ **Deletion** – delete an element at given index.
- ❑ **Search** – search an element using given index or by value.
- ❑ **Updation** – update an element at given index.
- ❑ **Sorting** – arranging the elements in some type of order.
- ❑ **Merging** – Combining two arrays into a single array
- ❑ **Reversing** – Reversing the elements

Default Value Initialization

In C, when an array is initialized with size, then it assigns following defaults values to its elements

- ❑ **bool** – false
- ❑ **char**– 0
- ❑ **float**– 0.0
- ❑ **double**– 0.0f
- ❑ **int**– 0

Basic Operation cont...



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Insertion

Insert operation is to insert one or more data elements into an array. Based on the requirement, new element can be added at the beginning or end or any given position of array.

Let LA is a Linear Array (unordered) with N elements and K is a positive integer such that $K \leq N$. Below is the algorithm where ITEM is inserted into the Kth position of LA. Procedure - **INSERT(LA, N, K, ITEM)**

1. Start
2. Set $J = N$
3. Set $N = N + 1$ /* Increase the array length by 1 */
4. Repeat steps 5 and 6 while $J \geq K$
5. Set $LA[J+1] = LA[J]$ /* Move the element downward */
6. Set $J = J - 1$ /* Decrease counter */
7. Set $LA[K] = \text{ITEM}$
8. Stop

Deletion

Deletion refers to removing an existing element from the array and re-organizing all elements of an array.

Consider LA is a linear array with N elements and K is a positive integer such that $K \leq N$. Below is the algorithm to delete an element available at the Kth position of LA. Procedure - **DELETE(LA, N, K)**

1. Start
2. Set $J = K$
3. Repeat step 4 while $J < N$
4. Set $LA[J] = LA[J+1]$ /* Move the element upward */
5. Set $N = N - 1$ /* Reduce the array length by 1 */
6. Stop

Basic Operation cont...



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Search

You can perform a search for array element based on its value or position.

Consider LA is a linear array with N elements. Below is the algorithm to find an element with a value of ITEM using sequential search.

Procedure - **SEARCH(LA, N, ITEM)**

1. Start
2. Set $J=1$ and $LOC = 0$
3. Repeat steps 4 and 5 while $J < N$
4. IF $(LA[J] = ITEM)$ THEN $LOC = J$ AND GOTO STEP 6
5. Set $J = J + 1$
6. IF $(LOC > 0)$ PRINT J, ITEM ELSE PRINT 'Item not found'
7. Stop

Updation

Update operation refers to updating an existing element from the array at a given position.

Consider LA is a linear array with N elements and K is a positive integer such that $K \leq N$.

Below is the algorithm to update an ITEM available at the Kth position of LA. Procedure - **UPDATE(LA, N, K, ITEM)**

1. Start
2. Set $LA[K] = ITEM$
3. Stop

Basic Operation cont...



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Traversal

Traversal operation refers to printing the contents of each element or to count the number of elements with a given property

Consider LA is a linear array with N elements. Below is the algorithm to print each element.

Procedure - **TRAVERSE(LA, N)**

1. Start
2. Set J=1
3. Repeat steps 4 and 5 while J < N
4. PRINT LA[J]
5. Set J = J + 1
6. Stop

Sorting

Sorting operation refers to arranging the elements either in ascending or descending way.

Consider LA is a linear array with N elements. Below is the **Bubble Sort algorithm** to sort the elements in ascending order. Procedure - **SORT(LA, N)**

1. Start
2. Set I = 0
3. Set J = 0
4. Repeat steps 5,6,7 and 8 while I < N
5. J = I + 1
6. Repeat steps 7 and 8 while j < N
7. IF LA[I] is > LA[J] THEN
8. Set TEMP = LA[I]; LA[I] = LA[J]; LA[J] = TEMP;
9. Stop

Basic Operation cont...



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Merging - Assignment 1

Merging refers to combining two sorted arrays into one sorted array. It involves 2 steps –

- ❑ Sorting the arrays that are to be merged
- ❑ Adding the sorted elements of both arrays to a new array in sorted order

LA1 is a linear array with N elements, LA2 is a linear array with M elements and LA3 is a linear array with M+N elements. Write the algorithm to sort LA1 & LA2 and merge LA1 & LA2 into LA3 & sort LA3 and print each element of LA3

1. Start
- /* Assignment1 */**
2. Stop

Reversing - Assignment 2

Reversing refers to reversing the elements in the array by swapping the elements. Swapping should be done only half times of the array size

Consider LA is a linear array with N elements. Write the algorithm to reverse the elements and print each element of LA

1. Start
- /* Assignment 2 */**
2. Stop

Assignments



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Assignment 3

LA is a linear array with N elements. Write the algorithm to find the largest number and count the occurrence of the largest number

1. Start

/* Assignment 3 steps */

2. Stop

Assignment 4

LA is a linear array with N elements. Write the algorithm to copy the elements from LA to a new array LB

1. Start

/* Assignment 4 steps */

2. Stop

Assignment 5

LA is a linear array with N elements. Write the algorithm to transpose the array

1. Start

/* Assignment 5 steps */

2. Stop

Assignment 6

LA is a linear **sorted** array with N elements. Write the algorithm to insert ITEM to the array

1. Start

/* Assignment 6 steps */

2. Stop

Polynomials



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Polynomial is an expression constructed from one or more variables and constants, using only the operations of addition, subtraction, multiplication, and constant positive whole number exponents. A term is made up of coefficient and exponent.

Examples –

- ❑ Polynomial with single variable $P(X) = 4X^3 + 6X^2 + 7X + 9$ (4,6,7 are coefficient & 3,2 are exponent)
- ❑ Polynomial with 2 variables $P(X, Y) = X^3 - 2XY + 1$ (2 is coefficient & 3 is exponent)

Definition–

- ❑ Polynomial with single variable $P(X) = \sum_{k=0}^n a_k x^k = a_0 + a_1 x + a_2 x^2 + \dots + a_n x^n$

A polynomial thus may be **represented using arrays**. Array representation assumes that the exponents of the given expression are arranged from 0 to the highest value (**degree**), which is represented by the subscript of the array beginning with 0. The **coefficients** of the respective exponent are placed at an appropriate index in the array. Considering single variable polynomial expression, array representation is

arr	9	7	6	4	(coefficients)
	0	1	2	3	(exponents)

Polynomial Addition



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Consider LA is a linear array with N elements and LB is a linear array with M elements. Below is the algorithm for polynomial addition

1. Start
2. Set $j = \text{maximum of } M \text{ or } N$
3. Create a sum array LSum[] of size J
4. IF (N is Greater Than or Equal to M) Then
 Copy LA[] to LSum[]
else
 Copy LB[] to LSum[]
5. IF (N is Greater Than M) then
 Traverse array LB[] and $\text{LSum}[i] = \text{LSum}[i] + \text{LB}[i]$
else
 Traverse array LA[] and $\text{LSum}[i] = \text{LSum}[i] + \text{LA}[i]$ while $i < j$
6. PRINT LSum
7. Stop

Polynomial Multiplication



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Given two polynomials represented by two arrays, below is the illustration of the multiplication of the given two polynomials.

Example :

Input: $A[] = \{5, 0, 10, 6\}$ and $B[] = \{1, 2, 4\}$

Output: $\text{prod}[] = \{5, 10, 30, 26, 52, 24\}$

The first input array represents " $5 + 0x^1 + 10x^2 + 6x^3$ "

The second array represents " $1 + 2x^1 + 4x^2$ "

And output is " $5 + 10x^1 + 30x^2 + 26x^3 + 52x^4 + 24x^5$ "

A	5	0	10	6	Coefficients
	0	1	2	3	Exponents

B	1	2	4	0	Coefficients
	0	2	2	3	Exponents

AXB

Prod	5	10	30	26	52	24	Coefficients
	0	2	2	3	4	5	Exponents

Polynomial Multiplication cont...



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Algorithm:

prod[0.. m+n-1] Multiply (A[0..m-1], B[0..n-1])

1. Start
2. Create a product array prod[] of size m+n-1.
3. Initialize all entries in prod[] as 0.
4. Travers array A[] and do following for every element A[i]
 Traverse array B[] and do following for every element B[j]
 $\text{prod}[i+j] = \text{prod}[i+j] + A[i] * B[j]$
5. return prod[]
6. Stop

Class Exercise



Given three polynomials represented by arrays, write an algorithm to multiply those

Matrix Addition



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Suppose A and B are two matrix arrays of order $m \times n$, and C is another matrix array to store the addition result. i, j are counters.

Step 1: Start

Step 2: Read: m and n

Step 3: Read: Take inputs for Matrix A[1:m, 1:n] and Matrix B[1:m, 1:n]

Step 4: Repeat for i := 1 to m by 1:

 Repeat for j := 1 to n by 1:

$C[i, j] := A[i, j] + B[i, j]$

 [End of inner for loop]

 [End of outer for loop]

Step 5: Print: Matrix C

Step 6: Stop

Matrix Multiplication



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Suppose A and B are two matrices and their order are respectively $m \times n$ and $p \times q$. i, j and k are counters. And C to store result.

Step 1: Start.

Step 2: Read: m, n, p and q

Step 3: Read: Inputs for Matrices $A[1:m, 1:n]$ and $B[1:p, 1:q]$.

Step 4: If $n \neq p$ then:

 Print: Multiplication is not possible.

Else:

 Repeat for $i := 1$ to m by 1:

 Repeat for $j := 1$ to q by 1:

$C[i, j] := 0$ [Initializing]

 Repeat $k := 1$ to n by 1

$C[i, j] := C[i, j] + A[i, k] \times B[k, j]$

 [End of for loop]

 [End of for loop]

 [End of for loop]

 [End of If structure]

Step 5: Print: $C[1:m, 1:q]$

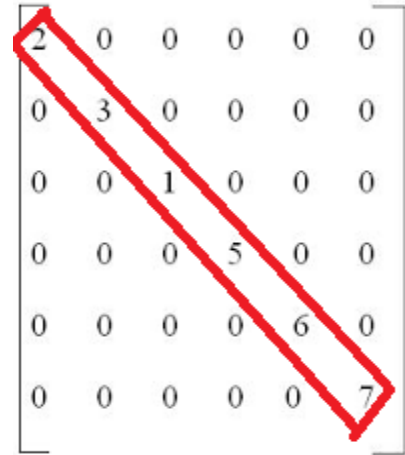
Step 6: Stop

Sparse Matrix



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A **sparse matrix** is a two-dimensional array in which most of the elements are zero or null. It is a wastage of memory and processing time if we store null values or 0 of the matrix in an array. For example, consider a matrix of size 100 X 100 containing only 10 non-zero elements. In this matrix, only 10 spaces are filled with non-zero values and remaining spaces of matrix are filled with 0. That means, totally we allocate $100 \times 100 \times 2 = 20000$ bytes of space to store this integer matrix and to access these 10 non-zero elements we have to make scanning for 10000 times.

A 6x6 matrix is shown with a red diagonal line from the top-left to the bottom-right. The non-zero elements are located at (1,1)=2, (2,2)=3, (3,3)=1, (4,4)=5, (5,5)=6, and (6,6)=7. All other elements are 0.

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

To avoid such circumstances different techniques such as **linked list** or **triplet** are used

Linked List Representation will be covered later

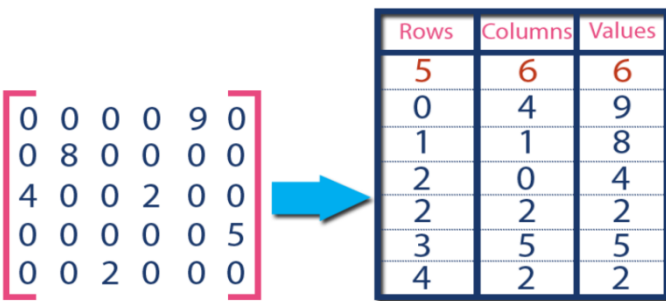
Sparse Matrix Triplet Representation



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In this representation, only non-zero values are considered along with their row and column index values. In this representation, the 0th row stores total rows, total columns and total non-zero values in the matrix. For example, consider a matrix of size 5 X 6 containing 6 number of non-zero values. This matrix can be represented as shown in the image...

2 D Array Row Representation



Rows	Columns	Values
5	6	6
0	4	9
1	1	8
2	0	4
2	2	2
3	5	5
4	2	2

2D array is used to represent a sparse matrix in which there are three columns named as

- **Rows:** Index of row, where non-zero element is located
- **Columns:** Index of column, where non-zero element is located.
- **Values:** Value of the non zero element located at index – (row, column)

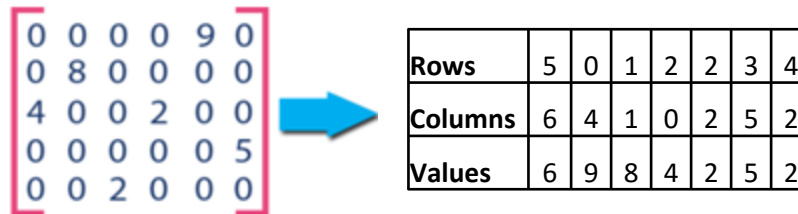
In above example matrix, there are 6 non-zero elements (those are 9, 8, 4, 2, 5 & 2) and matrix size is 5 X 6. We represent this matrix as shown in the above image. The first row is filled with values 5, 6 & 6 which indicates that it is a sparse matrix with 5 rows, 6 columns & 6 non-zero values. Second row is filled with 0, 4, & 9 which indicates the value in the matrix at 0th row, 4th column is 9. In the same way the remaining non-zero values also follows the similar pattern.

Sparse Matrix Triplet Representation



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2 D Array Columnar Representation



2D array is used to represent a sparse matrix in which there are three rows named as

- **Rows:** Index of row, where non-zero element is located
- **Columns:** Index of column, where non-zero element is located.
- **Values:** Value of the non zero element located at index – (row, column)

In above example matrix, there are 6 non-zero elements (those are 9, 8, 4, 2, 5 & 2) and matrix size is 5 X 6. We represent this matrix as shown in the above image. The first column is filled with values 5, 6 & 6 which indicates that it is a sparse matrix with 5 rows, 6 columns & 6 non-zero values. Second column is filled with 0, 4, & 9 which indicates the value in the matrix at 0th row, 4th column is 9. In the same way the remaining non-zero values also follows the similar pattern.



Sparse Matrix Triplet Representation – C Code

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// Assume 4x5 matrix

```
int matrix[4][5] =  
{  
    {0, 0, 3, 0, 4}, {0, 0, 5, 7, 0}, {0, 0, 0, 0, 0}, {0, 2, 6, 0, 0}  
};
```

//Calculating number of non-zero entries

```
int size = 0;  
for (int i = 0; i < 4; i++)  
    for (int j = 0; j < 5; j++)  
        if (matrix[i][j] != 0) {size++; }
```

2 D Array Row Representation

// number of rows = size+1 and columns = 3

```
int sparseMatrix[size+1][3];  
// Making of new matrix  
int k = 1;  
sparseMatrix[0][0] = 4; //filling no. or rows  
sparseMatrix[0][1] = 5; //filling no. or columns  
sparseMatrix[0][2] = size //filling no. of non-zero values  
for (i = 0; i < 4; i++)  
    for (j = 0; j < 5; j++)  
        if (matrix[i][j] != 0) {  
            sparseMatrix[k][0] = i;  
            sparseMatrix[k][1] = j;  
            sparseMatrix[k][2] = matrix[i][j];  
            k++;  
        }
```

2 D Array Columnar Representation

// number of rows = 3 and columns = size+1

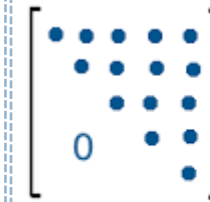
```
int sparseMatrix[3][size+1];  
// Making of new matrix  
int k = 1;  
sparseMatrix[0][0] = 4; //filling no. or rows  
sparseMatrix[1][0] = 5; //filling no. or columns  
sparseMatrix[2][0] = size //filling no. of non-zero values  
for (i = 0; i < 4; i++)  
    for (j = 0; j < 5; j++)  
        if (matrix[i][j] != 0) {  
            sparseMatrix[0][k] = i;  
            sparseMatrix[1][k] = j;  
            sparseMatrix[2][k] = matrix[i][j];  
            k++;  
        }
```

Sparse Matrix cont...

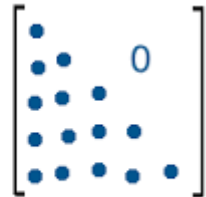


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N-square sparse matrices is called **triangular matrix**. A square matrix is called **lower triangular** if all the entries above the main diagonal are zero. Similarly, a square matrix is called **upper triangular** if all the entries below the main diagonal are zero.



Upper Triangular Matrix



Lower Triangular Matrix

Matrix where nonzero entries can only occur on the diagonal or on elements immediately above or below the diagonal is called a **tridiagonal matrix**

$$\begin{pmatrix} -4 & 1 & 0 & 0 & 0 \\ 1 & -4 & 1 & 0 & 0 \\ 0 & 1 & -4 & 1 & 0 \\ 0 & 0 & 1 & -4 & 1 \\ 0 & 0 & 0 & 1 & -4 \end{pmatrix}$$

Class Work



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Design array based data structure to represent

- ☐ Lower Triangular matrix
- ☐ Upper Triangular matrix
- ☐ Tri-diagonal matrix

Assignments



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Assignment 7

Write an algorithm to add the original sparse matrix with the transpose of the same matrix.

1. Start

/* Assignment 7 steps */

2. Stop

Assignment 8

Write an algorithm to multiply two sparse matrices.

1. Start

/* Assignment 8 steps*/

2. Stop

Assignment 9

9.1. Design an efficient data structure to store data for lower and upper triangular matrix.

9.2. Design an efficient data structure to store data for tri-diagonal matrix.

Assignment 10

Design an algorithm to convert a lower triangular matrix to upper triangular matrix.

1. Start

/* Assignment 10 steps */

2. Stop

Assignments cont...



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11. Write an algorithm that takes as input the size of the array and the elements in the array and a particular index and prints the element at that index.
12. Write down the algorithm to sort elements by their frequency.
13. Write down the algorithm to add two polynomials of single variable.
14. Write down the algorithm to multiply two polynomials of two variables.
15. A program P reads in 500 random integers in the range [0..100] presenting the scores of 500 students. It then prints the frequency of each score above 50. What would be the best way for P to store the frequencies?
16. Write down the algorithm to delete all the vowels in a character array.
17. Write down the algorithm to print all the elements below the minor diagonal in a 2-D array.
18. Write an algorithm to find a triplet that sum to a given value
19. Given an array arr, write an algorithm to find the maximum $j - i$ such that $\text{arr}[j] > \text{arr}[i]$
20. Write an algorithm to replace every element in the array with the next greatest element present in the same array.

Assignments cont...



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21. Write an algorithm that takes as input the size of the array and the elements in the array and find the median of the elements in the array.
22. Write an algorithm that takes as input the size of the array and the elements in the array and find the mode of the elements in the array.
23. Lower Triangular array –
 - What is the maximum number of non-zero elements?
 - How the elements can be stored sequentially in memory?
 - Develop an algorithm for accessing the array[i][j] where $i \geq j$
24. Upper Triangular array –
 - What is the maximum number of non-zero elements?
 - How the elements can be stored sequentially in memory?
 - Develop an algorithm for accessing the array[i][j] where $i \leq j$
25. Check board –
 - How a check board can be represented by array?
 - How to represent the state of a game of checkers at a particular instant?

**THANK
YOU!**

Home Work (HW)



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1. Write an algorithm to find whether an array is subset of another array
2. Write an algorithm to remove repeated elements in a given array.
3. Write down the algorithm to find the k 'th smallest and largest element in unsorted array
4. Write an algorithm to find the number of occurrence of k^{th} element in an integer array.
5. Write an algorithm to replace every array element by multiplication of previous and next
6. Consider the static array growing from both ends. Write the underflow and overflow condition for insertion and deletion from the perspective of both ends.
7. Given an array of integers, and a number 'sum'. Write an algorithm to find the number of pairs of integers in the array whose sum is equal to 'sum'.
Examples: Input : `arr[] = {1, 5, 7, -1}`, `sum = 6`
Output : 2 as Pairs with sum 6 are (1, 5) and (7, -1)

Home Work (HW)



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8. Given an unsorted array, Write down the algorithm to find the minimum difference between any pair in given array.
Input : {1, 5, 3, 19, 18, 25};
Output : 1 as Minimum difference is between 18 and 19
9. Given an array of integers, Write down the algorithm to count number of sub-arrays (of size more than one) that are strictly increasing.
Input: arr[] = {1, 2, 3, 4}
Output: 6 as there are 6 sub-arrays {1, 2}, {1, 2, 3}, {1, 2, 3, 4}, {2, 3}, {2, 3, 4} and {3, 4}
10. Given an array of integers. All numbers occur twice except one number which occurs once. Write down the algorithm to find the number in $O(n)$ time & constant extra space.
Input: ar[] = {7, 3, 5, 4, 5, 3, 4};
Output: 7
11. Given a 2D array of size $m \times n$, containing either 1 or 0. As we traverse through, where ever we encounter 0, we need to convert the whole corresponding row and column to 0, where the original value may or may not be 0. Devise an algorithm to solve the problem minimizing the time and space complexity.

Supplementary Reading



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- ❑ https://www.tutorialspoint.com/data_structures_algorithms/array_data_structure.htm
- ❑ <http://www.geeksforgeeks.org/array-data-structure/>
- ❑ <https://www.hackerrank.com/domains/data-structures/arrays>
- ❑ <http://javarevisited.blogspot.in/2015/06/top-20-array-interview-questions-and-answers.html#axzz4myAupUvT>
- ❑ <https://www.youtube.com/playlist?list=PLqM7alHxFySEQDk2MDfbwEdjd2svVJH9p>



❑ What is Array?

- ✓ Array is a collection of variables of same data type that share a common name.
- ✓ Array is an ordered set which consist of fixed number of elements.
- ✓ Array is an example of linier data structure.
- ✓ In array memory is allocated sequentially so it is also known as sequential list.

❑ 1-D Array address calculation

Address of $A[i] = BA + w * (i)$ where BA is the base address, w is the word length and i is the index

- ❑ **Row-Major order:** Row-Major Order is a method of representing multi dimension array in sequential memory. In this method elements of an array are arranged sequentially row by row. Thus elements of first row occupies first set of memory locations reserved for the array, elements of second row occupies the next set of memory and so on.

Address of $A[i][j] = BA + w * [n * (i - L_r) + (j - L_c)]$

- ❑ **Column-Major order:** Column-Major Order is a method of representing multi dimension array in sequential memory. In this method elements of an array are arranged sequentially column by column. Thus elements of first column occupies first set of memory locations reserved for the array, elements of second column occupies the next set of memory and so on.
Address of $A[i][j] = BA + w * [(i - L_r) + m * (j - L_c)]$
- ❑ **Array ADT:** The array is a basic abstract data type that holds an ordered collection of items accessible by an integer index. These items can be anything from primitive types such as integers to more complex types like instances of struct. Since it's an ADT, it doesn't specify an implementation, but is almost always implemented by an static array or dynamic array.
- ❑ Time Complexity of 2-D array traversal = $O(m*n)$
- ❑ Time Complexity of 1-D array traversal = $O(n)$
- ❑ Time complexity of accessing an element of an 2-D array = $O(m*n)$
- ❑ Time complexity of accessing an element of an 1-D array = $O(n)$

❑ Ragged 2 D Arrays:

```
char *font[] = {  
    (char []) {65,8,12,1,0,0x18, 0x3C, 0x66, 0xC3, 0xC3, 0xC3, 0xC3, 0xFF, 0xFF},  
    (char []) {39,2,3,4,9,0xC0,0xC0, 0xC0},  
    (char []) {46,2,2,4,0,0xC0,0xC0}};
```

