BMS INSTITUTE OF TECHNOLOGY

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DATA STRUCTURES AND APPLICATIONS

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MODULE 1: INTRODUCTION

DATA STRUCTURES

Data may be organized in many different ways. The logical or mathematical model of a particular organization of data is called a **data structure.**

The choice of a particular data model depends on the two considerations

1. It must be rich enough in structure to mirror the actual relationships of the data in the real world.
2. The structure should be simple enough that one can effectively process the dat a whenever necessary.

Basic Terminology: Elementary Data Organization:

Data: Data are simply values or sets of values.

Data items: Data items refers to a single unit of values.

Data items that are divided into sub-items are called **Group items**. Ex: An Employee Name may be divided into three subitems- first name, middle name, and last name.

Data items that are not able to divide into sub-items are called **Elementary items.**
Ex: SSN

Entity: An entity is something that has certain attributes or properties which may be assigned values. The values may be either numeric or non-numeric.

Ex:	Attributes-	Names,	Age,	Sex,	SSN
	Values-	Rohland Gail,	34,	F,	134-34-5533

Entities with similar attributes form an **entity set**. Each attribute of an entity set has a range of values, the set of all possible values that could be assigned to the particular attribute.
The term “information” is sometimes used for data with given attributes, of, in other words meaningful or processed data.

Field is a single elementary unit of information representing an attribute of an entity.

Record is the collection of field values of a given entity.

File is the collection of records of the entities in a given entity set.

Each record in a file may contain many field items but the value in a certain field may uniquely determine the record in the file. Such a field K is called a primary key and the values k1, k2, ….. in such a field are called keys or key values.

Records may also be classified according to length.
A file can have fixed-length records or variable-length records.

- In fixed-length records, all the records contain the same data items with the same amount of space assigned to each data item.
- In variable-length records file records may contain different lengths.

Example: Student records have variable lengths, since different students take differe nt numbers of courses. Variable-length records have a minimum and a maximum length.

The above organization of data into fields, records and files may not be complex enough to maintain and efficiently process certain collections of data. For this reason, data are also organized into more complex types of structures.

The study of complex data structures includes the following three steps:

1. Logical or mathematical description of the structure
2. Implementation of the structure on a computer
3. Quantitative analysis of the structure, which includes determining the amount of memory needed to store the structure and the time required to process the structure.

CLASSIFICATION OF DATA STRUCTURES

Data structures are generally classified into

- Primitive data Structures
- Non-primitive data Structures

1. **Primitive data Structures:** Primitive data structures are the fundamental data types which are supported by a programming language. Basic data types such as integer, real, character and Boolean are known as Primitive data Structures. These data types consists of characters that cannot be divided and hence they also called simple data types.

2. **Non- Primitive data Structures:** Non-primitive data structures are those data structures which are created using primitive data structures. Examples of non-primitive data structures is the processing of complex numbers, linked lists, stacks, trees, andgraphs.

Based on the structure and arrangement of data, non-primitive data structures is further classified into

1. Linear Data Structure
2. Non-linear Data Structure

1. Linear Data Structure:

A data structure is said to be linear if its elements form a sequence or a linear list. There are basically two ways of representing such linear structure in memory.

1. One way is to have the linear relationships between the elements represented by means of sequential memory location. These linear structures are called arrays.
2. The other way is to have the linear relationship between the elements represented by means of pointers or links. These linear structures are called linked lists.

The common examples of linear data structure are Arrays, Queues, Stacks, Linked lists

2. Non-linear Data Structure:

A data structure is said to be non-linear if the data are not arranged in sequence or a linear. The insertion and deletion of data is not possible in linear fashion. This structure is mainly used to represent data containing a hierarchical relationship between elements. Trees and graphs are the examples of non-linear data structure.

Arrays:

The simplest type of data structure is a linear (or one dimensional) array. A list of a finite number *n* of similar data referenced respectively by a set of *n* consecutive numbers, usually 1, 2, 3 . . . . *n*. if **A** is chosen the name for the array, then the elements of **A** are denoted by subscript notation $a_1, a_2, a_3 \ldots\ldots a_n$

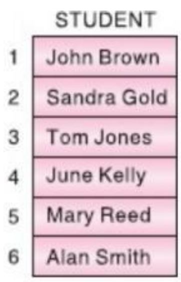
or

by the parenthesis notation A (1), A (2), A (3) . . . . . . A (n)

or

by the bracket notation A [1], A [2], A [3] . . . . . . A [n]

Example 1: A linear array STUDENT consisting of the names of six students is pictured in below figure. Here STUDENT [1] denotes John Brown, STUDENT [2] denotes Sandra Gold, and so on.



Linear arrays are called one-dimensional arrays because each element in such an array is referenced by one subscript. A two-dimensional array is a collection of similar data elements where each element is referenced by two subscripts.

<u>Example 2:</u> A chain of 28 stores, each store having 4 departments, may list its weekly sales as in below fig. Such data can be stored in the computer using a two-dimensional array in which the first subscript denotes the store and the second subscript the department. If SALES is the name given to the array, then
SALES [1, 1] = 2872, SALES [1, 2] - 805, SALES [1, 3] = 3211,…., SALES [28, 4] = 982

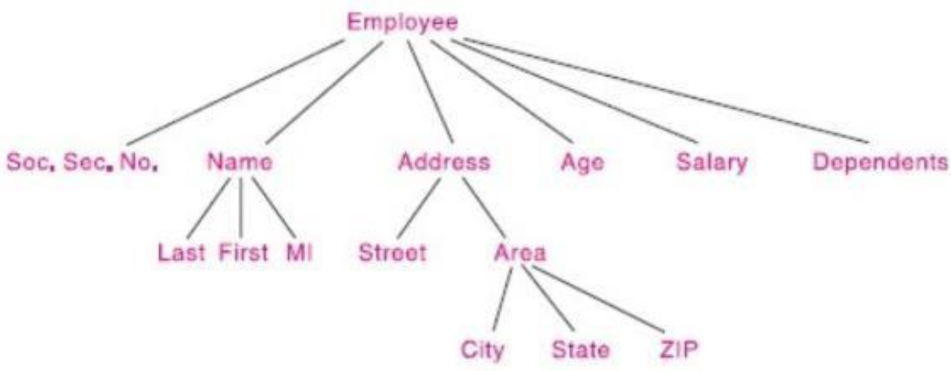
Store \ Dept.	1	2	3	4
1	2872	805	3211	1560
2	2196	1223	2525	1744
3	3257	1017	3686	1951
. . .	. . .	. . .	. . .	. . .
28	2618	931	2333	982

<u>Trees</u>

Data frequently contain a hierarchical relationship between various elements. The data structure which reflects this relationship is called a <u>rooted tree graph</u> or a <u>tree</u>.
Some of the basic properties of tree are explained by means of examples

<u>Example 1: Record Structure</u>
Although a file may be maintained by means of one or more arrays a record, where one indicates both the group items and the elementary items, can best be described by means of a tree structure.
For example, an employee personnel record may contain the following data items:
Social Security Number, Name, Address, Age, Salary, Dependents

However, Name may be a group item with the sub-items Last, First and MI (middle initial). Also Address may be a group item with the subitems Street address and Area address, where Area itself may be a group item having subitems City, State and ZIP code number.
This hierarchical structure is pictured below



(a)

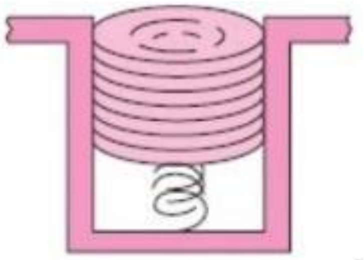
Another way of picturing such a tree structure is in terms of levels, as shown below

```
01 Employee
     02 Social Security Number
     02 Name
          03 Last
          03 First
          03 Middle Initial
     02 Address
          03 Street
          03 Area
               04 City
               04 State
               04 ZIP
     02 Age
     02 Salary
     02 Dependents
```

(b)

<u>Some of the data structures are briefly described below.</u>

<u>1.</u> **<u>Stack:</u>** A stack, also called a fast-in first-out (LIFO) system, is a linear list in which insertions and deletions can take place only at one end, called the top. This structure is similar in its operation to a stack of dishes on a spring system as shown in fig.
Note that new 4 dishes are inserted only at the top of the stack and dishes can be deleted only from the top of the Stack.



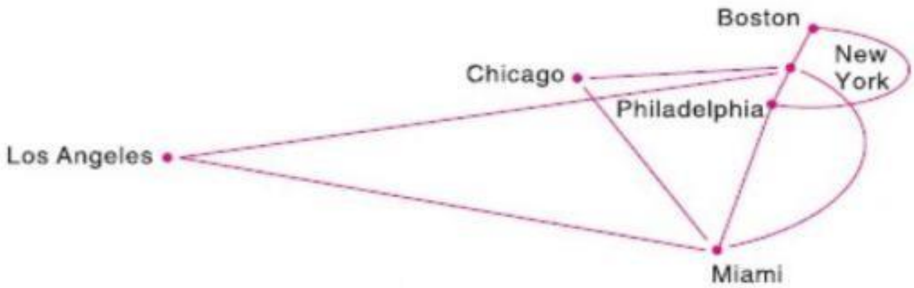
(a) Stack of dishes

2. **Queue:** A queue, also called a first-in first-out (FIFO) system, is a linear list in which deletions can take place only at one end of the list, the "from" of the list, and insertions can take place only at the other end of the list, the "rear" of the list.

This structure operates in much the same way as a line of people waiting at a bus stop, as pictured in Fig. the first person in line is the first person to board the bus. Another analogy is with automobiles waiting to pass through an intersection the first car in line is the first car through.

Queue waiting for a bus

3. **Graph:** Data sometimes contain a relationship between pairs of elements which is not necessarily hierarchical in nature. For example, suppose an airline flies only between the cities connected by lines in Fig. The data structure which reflects this type of relationship is called a graph.



Airline flights

DATA STRUCTURES OPERATIONS

The data appearing in data structures are processed by means of certain operations.
The following four operations play a major role in this text:

1. **Traversing:** accessing each record/node exactly once so that certain items in the record may be processed. (This accessing and processing is sometimes called "**visiting**" the record.)
2. **Searching:** Finding the location of the desired node with a given key value, or finding the locations of all such nodes which satisfy one or more conditions.
3. **Inserting:** Adding a new node/record to the structure.
4. **Deleting:** Removing a node/record from the structure.

The following two operations, which are used in special situations:

1. **Sorting:** Arranging the records in some logical order (e.g., alphabetically according to some NAME key, or in numerical order according to some NUMBER key, such as social security number or account number)
2. **Merging:** Combining the records in two different sorted files into a single s orted file.

ARRAYS

- An Array is defined as, an ordered set of similar data items. All the data items of an array are stored in consecutive memory locations.
- The data items of an array are of **same type** and each data items can be accessed using the same **name** but different **index** value.
- An array is a set of pairs, <*index, value* >, such that each index has a value associated with it. It can be called as ***corresponding*** or a ***mapping***

Ex: <index, value>

< 0 , 25 >	list[0]=25
< 1 , 15 >	list[1]=15
< 2 , 20 >	list[2]=20
< 3 , 17 >	list[3]=17
< 4 , 35 >	list[4]=35

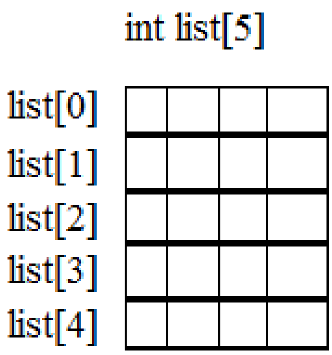
Here, ***list*** is the name of array. By using, list [0] to list [4] the data items in list can be accessed.

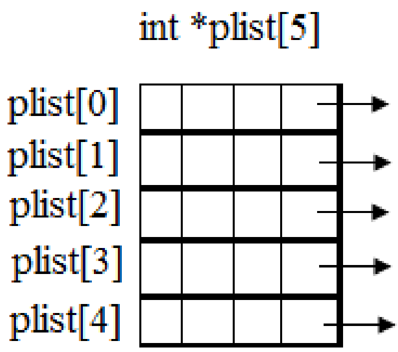
Array in C

Declaration: A one dimensional array in C is **declared** by adding brackets to the name of a variable.

Ex: **int list[5], *plist[5];**

- The array **list[5],** defines 5 integers and in C array start at index 0, so list[0], list[1], list[2], list[3], list[4] are the names of five array elements which contains an integer value.
- The array ***plist[5],** defines an array of 5 pointers to integers. Where, plist[0], plist[1], plist[2], plist[3], plist[4] are the five array elements which contains a pointer to an integer.





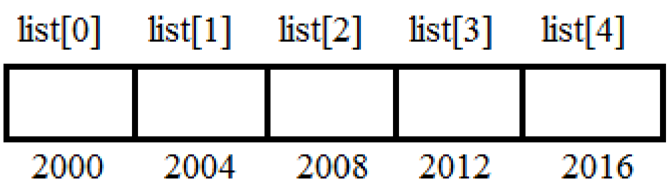
<u>Implementation:</u>

- When the complier encounters an array declaration, **list[5],** it allocates five consecutive memory locations. Each memory is enough large to hold a single integer.
- The address of first element of an array is called **Base Address.** Ex: For **list[5] t**he address of **list[0]** is called the base address.
- If the memory address of **list[i]** need to compute by the compiler, then the size of the **int** would get by **sizeof (int)**, then memory address of list[i] is as follows:

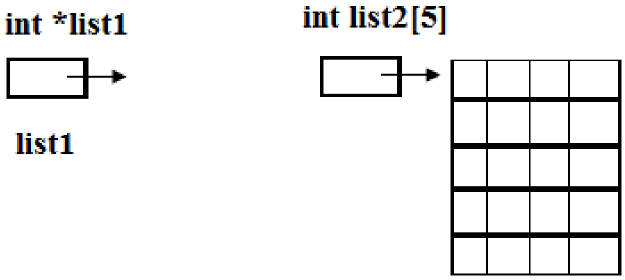
$$\textbf{list[i]} = \alpha + i * \textbf{sizeof (int)}$$

Where, α is base address.

list[3] = α+ 3 * sizeof(int)
= 2000 + 3 * 4
list[3] = 2012



<u>Difference between **int *list1; & int list2[5];**</u>
The variables **list1** and **list2** are both pointers to an **int,** but in **list2[5]** five memory locations are reserved for holding integers. **list2** is a pointer to **list2[0]** and **list2+i** is a pointer to **list2[i]**.



Note: In **C** the offset ***i*** do not multiply with the size of the type to get to the appropriate element of the array. Hence **(list2+i)** is equal **&list2[i]** and ***(list2+i)** is equal to **list2[i].**

<u>How C treats an array when it is parameter to a function?</u>

- All parameters of a C functions must be declared within the function. As various parameters are passed to functions, the name of an array can be passed as parameter.
- The range of a one-dimensional array is defined only in the main function since new storage for an array is not allocated within a function.
- If the size of a one dimensional array is needed, it must be passed into function as a argument or accessed as a global variable.

Example: Array Program

```
#define MAX_SIZE 100
float sum(float [], int);
float input[MAX_SIZE], answer;
void main(void)
{
        int i;
        for( i=0; i<MAX_SIZE;  i++)
        input[i]=  i;
        answer = sum(input, MAX_SIZE);
        printf("\n The sum is: %f \n",answer);
}

float sum(float list[], int n)
{
        int i;
        float tempsum = 0;
        for(i=0; i<n; i++)
                tempsum = tempsum + list[i];
        return tempsum;
}
```

When **sum** is invoked, **input=&input[0]** is copied into a temporary location and associated with the formal parameter ***list***

A function that prints out both the address of the *i*th element of the array and the value found at that address can written as shown in below program.

```
void print1 (int *ptr, int rows)
{
        int i;
        printf(" Address contents \n");
        for(i=0; i<rows; i++)
                printf("% 8u %5d \n", ptr+i, *(prt+i));
        printf("\n");
}
```

Output:

Address	**Content**
12244868	0
12344872	1
12344876	2
12344880	3
12344884	4

STRUCTURES

A structure is a collection of related information of possibly different datatype under one name..

Syntax: struct

```
        {       data_type member 1;
                data_type  member 2;
                ………………………
                ………………………
                data_type   member n;
        } variable_name;
```

Ex:

```
struct {
                char name[10];
                int age;
                float salary;
        }Person
```

The above example creates a **structure** and variable name is **Person** and that has three fields:
name = a name that is a character array

age = an integer value representing the age of the person

salary = a float value representing the salary of the individual

Note:

*)Just by defining a structure, memory will not be allocated for the various fields. It simply describes a format called template to represent information as shown

name	Array of 20 characters
marks1	Integer
marks2	Integer
marks3	Integer
regno	Array of 10 characters

*)If the structure is associated with a variable then the memory is allocated.

Assign values to fields

To assign values to the fields, use **.** (dot) as the structure member operator. This operator is used to select a particular member of the structure

Ex:
```
strcpy(Person.name,"james");
Person.age = 10;
Person.salary = 35000;
```

Type-Defined Structure

The structure definition associated with keyword **typedef** is called Type-Defined Structure.

Syntax 1: typedef struct
```
{
    data_type member 1;
    data_type member 2;
    ………………………
    ………………………
    data_type member n;
}Type_name;
```


Where,

- **typedef** is the keyword used at the beginning of the definition and by using typedef user defined data type can be obtained.
- **struct** is the keyword which tells structure is defined to the complier
- The members are declare with their data_type
- **Type_name** is not a variable, it is user defined data_type.

Syntax 2: struct struct_name
```
{
    data_type member 1;
    data_type member 2;
    ………………………
```

```
                ………………………
                data_type member n;
        };
    typedef struct struct_name Type_name;
```

Ex: **typedef struct**{

```
            char name[10];
            int age;
            float salary;
        }humanBeing;
```

In above example, **humanBeing** is the name of the type and it is a user defined data type.

Declarations of structure variables:

```
humanBeing  person1, person2;
```

This statement declares the variable **person1** and **person2** are of type **humanBeing.**

Structure Operation

The various operations can be performed on structures and structure members.

1. Structure Equality Check:

Here, the equality or inequality check of two structure variable of same type or dissimilar type is not allowed

```
typedef struct{
            char name[10];
            int age;
            float salary;
        }humanBeing;
humanBeing person1, person2;
```

if (person1 = = person2) is invalid.

The **valid function** is shown below

```
#define FALSE 0
#define TRUE 1
if (humansEqual(person1,person2))
    printf("The two human beings are the same\n");
else
    printf("The two human beings are not the same\n");
```

```
int humansEqual(humanBeing person1, humanBeing person2)
   { /* return TRUE if person1 and person2 are the same human being otherwise
              return FALSE */
      if (strcmp(person1.name, person2.name))
              return FALSE;
      if (person1.age != person2.age)
              return FALSE;
      if (person1.salary != person2.salary)
              return FALSE;
      return TRUE;
    }
```

Program: Function to check equality of structures

2. Assignment operation on Structure variables:

person1 = person2

The above statement means that the value of every field of the structure of person 2 is assigned as the value of the corresponding field of person 1, but this is invalid statement.

Valid Statements is given below:

```
strcpy(person1.name, person2.name);
person1.age = person2.age;
person1.salary = person2.salary;
```

Structure within a structure:

There is possibility to embed a structure within a structure. There are 2 ways to embed structure.

1. The structures are defined separately and a variable of structure type is declared inside the definition of another structure. The accessing of the variable of a structure type that are nested inside another structure in the same way as accessing other member of that structure

Example: The following example shows two structures, where both the structure are defined separately.

```
typedef struct {
        int month;
        int  day;
        int year;
    }date;

typedef struct {
        char name[10];
        int age;
        float salary;
        date dob;
    } humanBeing;
humanBeing person1;
```

A person born on February 11, 1944, would have the values for the date struct set as:

```
person1.dob.month = 2;
person1.dob.day = 11;
person1.dob.year = 1944;
```

2. The complete definition of a structure is placed inside the definition of another structure.

Example:

```
typedef struct {
        char name[10];
        int age;
        float salary;
        struct {
            int month;
            int  day;
            int year;
        } date;
    } humanBeing;
```

SELF-REFERENTIAL STRUCTURES

A self-referential structure is one in which one or more of its components is a pointer to itself. Self-referential structures usually require dynamic storage management routines (malloc and free) to explicitly obtain and release memory.

Consider as an example:

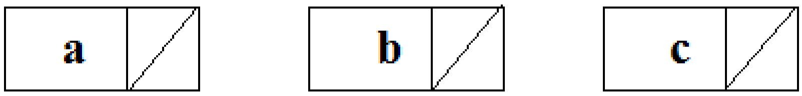
```
typedef struct {
        char data;
        struct list *link ;
    } list;
```

Each instance of the structure **list** will have two components **data** and **link**.

- **Data:** is a single character,
- **Link:** link is a pointer to a list structure. The value of link is either the address in memory of an instance of list or the null pointer.

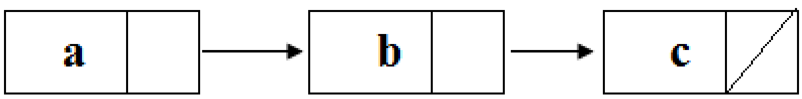
Consider these statements, which create three structures and assign values to their respective fields:

```
list item1, item2, item3;
item1.data = 'a';
item2.data = 'b';
item3.data = 'c';
item1.link = item2.1ink = item3.link = NULL;
```



Structures item1, item2 and item3 each contain the data item **a, b,** and **c** respectively, and the null pointer. These structures can be attached together by replacing the **null link** field in item 2 with one that points to item 3 and by replacing the null link field in item 1 with one that points to item 2.

```
item1.link = &item2;
item2.1ink = &item3;
```



Unions:

A union is similar to a structure, it is collection of data similar data type or dissimilar.

Syntax:

```
union{
        data_type   member 1;
        data_type   member 2;
        ……………………….
        ……………………….
        data_type   member n;
    }variable_name;
```

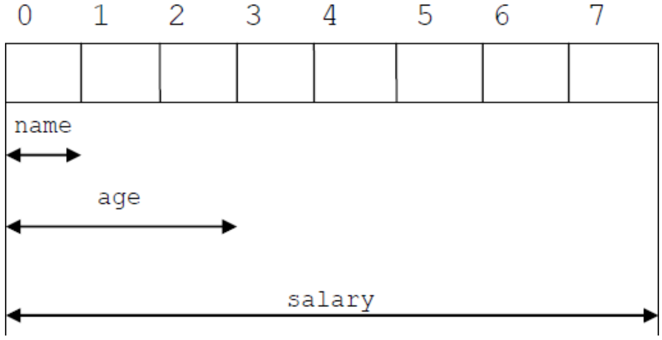
Example:

```
union{
        int children;
        int beard;
    } u;
```

Union Declaration:

A union declaration is similar to a structure, but the fields of a union must share their memory space. This means that only one field of the union is "active" at any given time.

```
union{
        char name;
        int age;
        float salary;
    }u;
```



The major difference between a union and a structure is that unlike structure members which are stored in separate memory locations, all the members of union must share the same memory space. This means that only one field of the union is "active" at any given time.

Example:

```
#include <stdio.h>
union job {
            char name[32];
            float salary;
            int worker_no;
           }u;

int main( ){
            printf("Enter name:\n");
            scanf("%s", &u.name);
            printf("Enter salary: \n");
            scanf("%f", &u.salary);
            printf("Displaying\n Name :%s\n",u.name);
            printf("Salary: %.1f",u.salary);
            return 0;
     }
```

Output:

Enter name: Albert

Enter salary: 45678.90

Displaying

Name: f%gupad (Garbage Value)

Salary: 45678.90

Comparison of structures and unions

Structure	Union
1.The keyword **struct** is used to define a structure	1. The keyword union is used to define a union.
2. When a variable is associated with a structure, the compiler allocates the memory for each member. The size of structure is greater than or equal to the sum of sizes of its members. The smaller members may end with unused slack bytes.	2. When a variable is associated with a union, the compiler allocates the memory by considering the size of the largest memory. So, size of union is equal to the size of largest member.
3. Each member within a structure is assigned unique storage area of location.	3. Memory allocated is shared by individual members of union.
4. The address of each member will be in ascending order This indicates that memory for each member will start at different offset values.	4. The address is same for all the members of a union. This indicates that every member begins at the same offset value.
5 Altering the value of a member will not affect other members of the structure.	5. Altering the value of any of the member will alter other member values.
6. Individual member can be accessed at a time	6. Only one member can be accessed at a time.
7. Several members of a structure can initialize at once.	7. Only the first member of a union can be initialized.

Difference between structures and arrays

Arrays	Structures
An array is a collection of related data elements of same data type	Structure is a collection of variables of similar or dissimilar data type
An array item can be accessed by using its subscript nr by using dereferencing / indirection (*) operator for pointers.	Structure items can be accessed using '.' or by using → for pointers

POINTERS

A pointer is a variable which contains the address in memory of another variable.

The two most important operator used with the pointer type are

& - The unary operator ***&*** which gives the address of a variable

* - The indirection or dereference operator * gives the content of the object pointed to by a pointer.

Declaration

int i, *pi;

Here, ***i*** is the integer variable and ***pi*** is a pointer to an integer

pi = &i;

Here, &i returns the address of ***i*** and assigns it as the value of ***pi***

Null Pointer

The null pointer points to no object or function.
The null pointer is represented by the integer 0.
The null pointer can be used in relational expression, where it is interpreted as false.

Ex: if (pi == NULL) or if (!pi)

Pointers can be Dangerous:

Pointer can be very dangerous if they are misused. The pointers are dangerous in following situations:

1. Pointer can be dangerous when an attempt is made to access an area of memory that is either out of range of program or that does not contain a pointer reference to a legitimate object.

Ex: main ()
```
{
    int *p;
    int pa = 10;
    p = &pa;
    printf("%d", *p);     //output = 10;
    printf("%d", *(p+1)); //accessing memory which is  out of range
}
```
2. It is dangerous when a NULL pointer is de-referenced, because on some computer it may return 0 and permitting execution to continue, or it may return the result stored in location zero, so it may produce a serious error.

3. Pointer is dangerous when use of explicit **type casts** in converting between pointer types

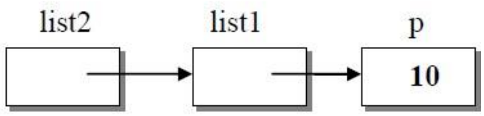
Ex:
```
pi = malloc (sizeof (int));
pf = (float*) pi;
```

4. In some system, pointers have the same size as type **int**, since **int** is the default type specifier, some programmers omit the return type when defining a **function**. The return type defaults to **int** which can later be interpreted as a pointer. This has proven to be a dangerous practice on some computer and the programmer is made to define explicit types for functions.

Pointers to Pointers

A variable which contains address of a pointer variable is called pointer -to-pointer.

Example:
```
int p;
int *list1, * *list2;
p=10;
list1=&p;
list2=&list1;
printf("%d, %d, %d", a, *list1, **list2);
```



Output: 10 10 10

DYNAMIC MEMORY ALLOCATION FUNCTIONS

It is the process of allocating memory space during run time. This type of memory allocation can be used in applications where the storage requirement is unpredictable. The following are the functions using which additional memory space can be allocated or unwanted space can be deleted, thereby optimizing space

Functions defined in (stdlib.h)

1. malloc
2. calloc
3. realloc
4. free

Comparison of Static and Dyanmic Memory Allocation

Sl.No	Static Memory Allocation	Dynamic Memory Allocation
1.	Memory is allocated during compile time	Memory is allocated during run time
2.	The size of the allocated memory space is fixed and it cannot be altered during execution.	The size of the allocated memory space is not fixed and it can be altered (increased / decreased) during execution.
3.	This type of memory allocation can be used in applications where the data size is fixed and known before processing.	This type of memory allocation can be used in applications where the storage requirement is unpredictable
4.	Execution is faster because memory is already allocated and only data manipulation is done.	Execution is slower because memory has to be allocated and only then data manipulation is done.
5.	Part of memory allocated is stack memory or global/static memory	Part of memory allocated is heap memory
6.	More space required	Less space required
7.	Memory cannot be reuse when it is no longer needed.	Memory can be freed when it is no longer needed & reuse or reallocate during execution.
8.	Ex: arrays	Ex: Dynamic arrays, linked _lisg>

1. malloc( ):

The function *malloc* allocates a user- specified amount of memory and a pointer to the start of the allocated memory is returned.

If there is insufficient memory to make the allocation, the returned value is NULL.

Syntax:

```
data_type  *x;
x= (data_type *) malloc(size);
```

Where,

x is a pointer variable of data_type

size is the number of bytes

Ex:
```
int *ptr;
ptr = (int *) malloc(100*sizeof(int));
```

2. calloc( ):

The function *calloc* allocates a user- specified amount of memory and initializes the allocated memory to **0** and a pointer to the start of the allocated memory is returned.
If there is insufficient memory to make the allocation, the returned value is NULL.

Syntax:

```
data_type  *x;
x= (data_type *) calloc(n, size);
```

Where,

x is a pointer variable of type int
n is the number of block to be allocated
size is the number of bytes in each block

Ex:

```
int *x
 x= calloc (10, sizeof(int));
```

The above example is used to define a one-dimensional array of integers. The capacity of this array is n=10 and x [0: n-1] (x [0, 9]) are initially 0

Macro CALLOC

```
#define CALLOC (p, n, s)\
if ( ! ((p) = calloc (n, s)))\
    {\
        fprintf(stderr, "Insuffiient memory");\
        exit(EXIT_FAILURE);\
    }\
```

Sl.No	**Basis Of Comparison**	**MALLOC()**	**CALLOC()**
1	No of blocks	Assigns single block of demanded memory.	Assigns multiple blocks of the requested memory.
2	Syntax	void *malloc(size_t size); **(Takes only one argument which is thesize of the block)**	void *calloc(size_t num, size_t size); **(Takes 2 arguments, first is number of blocks to be allocated and second is the size of each block)**
3	Initialization	malloc() doesn't clear and initialize the allocated memory.	The allocated memory is initialized to zero by using calloc().
4	Manner of Allocation	malloc() function allocates memory of size 'size' from the heap. Even if the memory is not available contiguously but available at different locations	calloc() function allocates memory the size of which is equal to num *size. This function can allocate the required number of blocks contiguously, if not available contiguously, return NULL
5	Speed	Fast,.So time efficiency is higher than calloc	Comparatively slow. calloc( ) is computationally more expensive because of zero filling but, occasionally, more convenient than malloc( )

3. realloc( ):

- Before using the realloc( ) function, the memory should have been allocated using malloc( ) or calloc( ) functions.
- The function relloc( ) resizes memory previously allocated by either ***mallor*** or ***calloc***, which means, the size of the memory changes by extending or deleting the allocated memory.
- If the existing allocated memory need to extend, the pointer value will not change.
- If the existing allocated memory cannot be extended, the function allocates a new block and copies the contents of existing memory block into new memory block and then deletes the old memory block.
- When realloc is able to do the resizing, it returns a pointer to the start of the new block and when it is unable to do the resizing, the old block is unchanged and the function returns the value NULL

Syntax:

```
data_type  *x;
x= (data_type *) realloc(p, s );
```

The size of the memory block pointed at by p changes to S. When **s > p** the additional **s-p** memory block have been extended and when **s < p**, then **p-s** bytes of the old block are freed.

Macro REALLOC

```
#define REALLOC(p,S)\
if (!((p) = realloc(p,s))) \
    { \
        fprintf(stderr, "Insufficient memory");\
        exit(EXIT_FAILURE);\
    }\
```

4. free( )

Dynamically allocated memory with either malloc( ) / calloc ( ) or realloc() does not return on its own. The programmer must use free( ) explicitly to release space.

Syntax:

```
free(ptr);
```

This statement cause the space in memory pointer by ptr to be deallocated

Problems with Dynamic Memory Allocation

1. **Memory Leakage**

This is a problem where in a part of the memory is reserved but is not accessible to imy of the applications.

Example: Consider the following program segment.

```
main ()
{
int *a;
a= (int *)malloc(sizeof (int) );
*a=l0;
a= (int *)malloc(sizeof (int) );
*a=20;
}
```

Here, the memory variable 'a' is allocated twice. However, 'a' contains the address of most recently allocated memory, thereby making the earlier allocated-memory inaccessible i.e. the memory location where the value 10 is stored is inaccessible to any of the application and is not possible to free so that it can be reused.

2. Dangling Pointer

Any pointer pointing to a destroyed object or which does not contain a valid-address is called a dangling pointer.

Example: Consider the following program segment

```
main()
{
}
int *a;
a =(int *)malloc(sizeof(int));
…….
……
*a=20;
free( a);
}
```

Here, if we de-allocate the memory for the variable 'a' using free(a), the memory location pointing to by it is returned to the free. Now the pointer variable 'a' can be used, but the contents pointed to that cannot be used, because the pointer variable ‘a’does not contain a valid address now and is called dangling_pointer.

Arrays

Arrays is a collection of items of similar data type. All elements of an array share a common name and each element in the array is identified by using the subscript/index.

Linear Array

A linear array is a list of a finite number *'n'* of homogeneous data element such that

a. The elements of the array are reference respectively by an index set consisting of n consecutive numbers.
b. The element of the array are respectively in successive memory locations.

The number *n* of elements is called the <u>length or size</u> of the array. The length or the numbers of elements of the array can be obtained from the index set by the formula

When LB = 0,

Length = UB – LB + 1

When LB = 1,

Length = UB

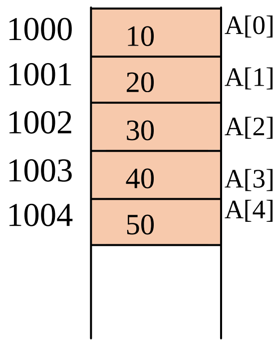
Where,

UB is the largest index called the <u>Upper Bound</u>

LB is the smallest index, called the <u>Lower Bound</u>

Representation of linear arrays in memory

Let LA be a linear array in the memory of the computer. The memory of the computer is simply a sequence of address location as shown below,



LOC (LA [K]) = address of the element LA [K] of the array LA

The elements of LA are stored in successive memory cells.

The computer does not keep track of the address of every element of LA, but needs to keep track only the address of the first element of LA denoted by, *Base* (LA)

and called the base address of LA.

Using the base address of LA, the computer calculates the address of any element of LA by the formula

$$\textbf{LOC (LA[K]) = } \textbf{\textit{Base}}\textbf{(LA) + w(K – lower bound)}$$

Where, w is the number of words per memory cell for the array LA.

DYNAMICALLY ALLOCATED ARRAYS

One Dimensional Array

While writing computer programs, if finds ourselves in a situation where we cannot determine how large an array to use, then a good solution to this problem is to defer this decision to run time and allocate the array when we have a good estimate of the required array size.

Example:

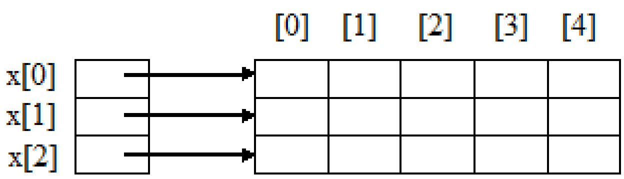
```
int i, n, *list;
printf("Enter the number of numbers to generate:");
scanf("%d", &n);
if(n<1)
        {
                fprintf (stderr, "Improper value of n \n");
                exit(EXIT_FAILURE);
        }
MALLOC (list, n*sizeof(int));
```

The programs fails only when n<1 or insufficient memory to hold the list of numbers that are to be sorted.

Two Dimensional Arrays

C uses array-of-arrays representation to represent a multidimensional array. The two dimensional arrays is represented as a one-dimensional array in which each element is itself a one-dimensional array.

Example: int x[3][5];



Array-of-arrays representation

C find element x[i][j] by first accessing the pointer in x[i].
Where **x[i] = α+ i* sizeof(int)**, which give the address of the zeroth element of row ***i*** of the array.
Then adding **j*sizeof(int)** to this pointer (**x[i]**) **,** the address of the [j]th element of row ***i*** is determined**.**

x[i] = α+ i* sizeof(int)
x[j] = α+ j* sizeof(int)
x[i][j] = x[i]+ i* sizeof(int)

Creation of Two-Dimensional Array Dynamically

```
int **myArray;
myArray = make2dArray(5,10);
myArray[2][4]=6;

int ** make2dArray(int  rows, int cols)
{ /* create a two dimensional rows X cols array */
        int **x, i;
        MALLOC(x, rows * sizeof (*x)); /*get memory for row pointers*/
        for (i= 0;i<rows;  i++)                    /* get memory for each row */
        MALLOC(x[i], cols * sizeof(**x));
        return x;
}
```

The second line allocates memory for a 5 by 10 two-dimensional array of integers and the third line assigns the value 6 to the [2][4] element of this array.

ARRAY OPERATIONS

- *Creating*
- *Traversing*
- *Inserting*
- *Deleting*
- *Sorting*
- *Searching*

1. Creating

Allocating memory space and create array of elements.

void create_ array()
```
{
int i ;
a= (int*)malloc(arraysize*sizeof(int));
if(a ==NULL)
{
printf(" array creation failed\n");
```

```
exit(0);
}
printf(("array created successfully\n."); - - - - - - -
printf("Enter %d e1ements\n", n)   //n is the  no of elements
for(i = 0; i < n; i++)
     {
         scanf("%d\t", &a[i]);
     }
```

2. Traversing

- Let A be a collection of data elements stored in the memory of the computer. Suppose if the contents of the each elements of array A needs to be printed or to count the numbers of elements of A with a given property can be accomplished by Traversing.
- Traversing is a accessing and processing each element in the array exactly once.

Algorithm 1: (Traversing a Linear Array)

Hear LA is a linear array with the lower bound LB and upper bound UB. This algorithm traverses LA applying an operation PROCESS to each element of LA using while loop.

1. [Initialize Counter] set K:= LB
2. Repeat step 3 and 4 while K ≤ UB
3. [Visit element] Apply PROCESS to LA [K]
4. [Increase counter] Set K:= K + 1
   [End of step 2 loop]
5. Exit

Algorithm 2: (Traversing a Linear Array)

Hear LA is a linear array with the lower bound LB and upper bound UB. This algorithm traverses LA applying an operation PROCESS to each element of LA using repeat – for loop.

1. Repeat for K = LB to UB
   Apply PROCESS to LA [K]
   [End of loop]
2. Exit.

Example:

Consider the array AUTO which records the number of automobiles sold e ach year from 1932 through 1984.

To find the number NUM of years during which more than 300 automobiles were sold, involves traversing AUTO.

1. [Initialization step.] Set NUM := 0
2. Repeat for K = 1932 to 1984:
   If AUTO [K] > 300, then: Set NUM: = NUM + 1.
   [End of loop.]
3. Return.

2. Inserting

- Let A be a collection of data elements stored in the memory of the computer. Inserting refers to the operation of adding another element to the collection A.
- Inserting an element at the "end" of the linear array can be easily done provided the memory space allocated for the array is large enough to accommodate the additional element.
- Inserting an element in the middle of the array, then on average, half of the elements must be moved downwards to new locations to accommodate the new element and keep the order of the other elements.

Algorithm:

INSERT (LA, N, K, ITEM)

Here LA is a linear array with N elements and K is a positive integer such that K ≤ N. This algorithm inserts an element ITEM into the K^{th} position in LA.

1. [Initialize counter] set J:= N
2. Repeat step 3 and 4 while J ≥ K
3. [Move J^{th} element downward] Set LA [J+1] := LA[J]
4. [Decrease counter] set J:= J – 1
   [End of step 2 loop]
5. [Insert element] set LA[K]:= ITEM
6. [Reset N] set N:= N+1
7. Exit

3. Deleting

- Deleting refers to the operation of removing one element to the collection A.
- Deleting an element at the "end" of the linear array can be easily done with difficulties.
- If element at the middle of the array needs to be deleted, then each subs equent elements be moved one location upward to fill up the array.

Algorithm

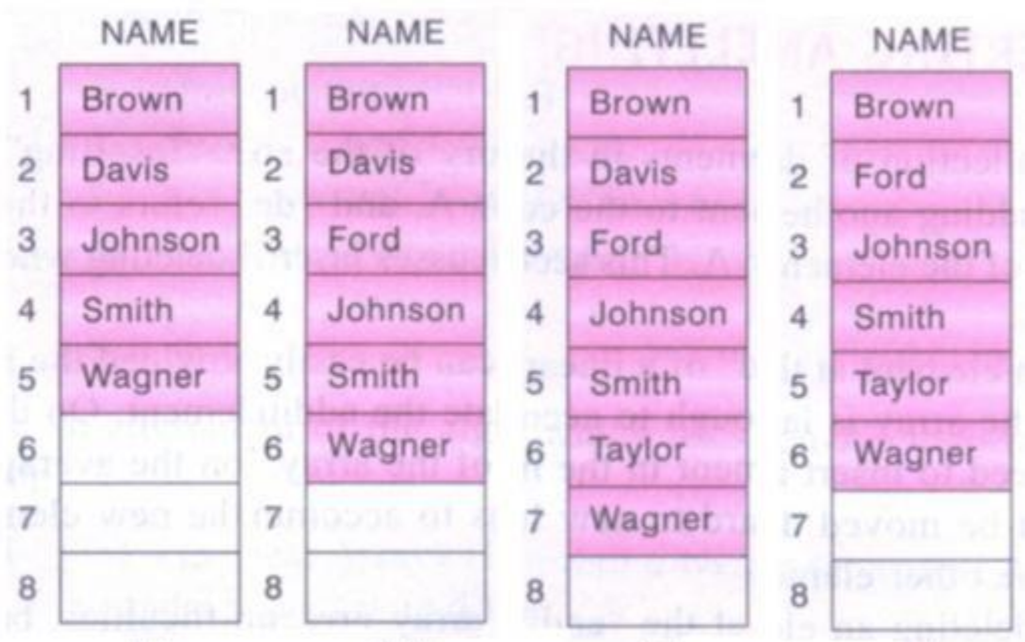
DELETE (LA, N, K, ITEM)

Here LA is a linear array with N elements and K is a positive integer such that K ≤ N. this algorithm deletes the K^{th} element from LA

1. Set ITEM:= LA[K]
2. Repeat for J = K to N – 1
   [Move J + 1 element upward] set LA[J]:= LA[J+1]
   [End of loop]
3. [Reset the number N of elements in LA] set N:= N – 1
4. Exit

Example: Inserting and Deleting

Suppose NAME is an 8-element linear array, and suppose five names are in the array, as in Fig.(a). Observe that the names are listed alphabetically, and suppose we want to keep the array names alphabetical at all times. Suppose ***Ford*** is added to the array. Then ***Johnson, Smith*** and ***Wagner*** must each be moved downward one location, as in Fig.(b). Next suppose Taylor is added to the array; then Wagner must be moved, as in Fig.(c). Last, suppose Davis is removed from the array. Then the five names Ford, Johnson, Smith, Taylor and Wagner must each be moved upward one location, as in Fig.(d).



(a) (b) (c) (d)

4. Sorting

Sorting refers to the operation of rearranging the elements of a list. Here list be a set of n elements. The elements are arranged in increasing or decreasing order.

Ex: suppose A is the list of n numbers. Sorting A refers to the operation of rearranging the elements of A so they are in increasing order, i.e., so that,

$$A[I] < A[2] < A[3] < ... < A[N]$$

For example, suppose A originally is the list

8, 4, 19, 2, 7, 13, 5, 16

After sorting, A is the list

2, 4, 5, 7, 8, 13, 16, 19

Bubble Sort

Suppose the list of numbers A[l], A[2], ... , A[N] is in memory. The bubble sort algorithm works as follows:

Algorithm: Bubble Sort – BUBBLE (DATA, N)

Here DATA is an array with N elements. This algorithm sorts the elements in DATA.

1. Repeat Steps 2 and 3 for K = 1 to N - 1.
2. Set PTR: = 1. [Initializes pass pointer PTR.]
3. Repeat while PTR ≤ N - K: [Executes pass.]

(a) If DATA[P TR] > DATA[P TR + 1], then:
Interchange DATA [PTR] and DATA [PTR + 1].
[End of If structure.]
(b) Set PTR: = PTR + 1.
[End of inner loop.]
[End of Step 1 outer loop.]
4. Exit.

Example:

Suppose the following numbers are stored in an array A:

32, 51, 27, 85, 66, 23, 13, 57

We apply the bubble sort to the array A. We discuss each pass separately.
Pass 1. We have the following comparisons:

(a) Compare A_1 and A_2. Since 32 < 51, the list is not altered.
(b) Compare A_2 and A_3. Since 51 > 27, interchange 51 and 27 as follows:

32, 27, 51, 85, 66, 23, 13, 57

(c) Compare A_3 and A_4. Since 51 < 85, the list is not altered.
(d) Compare A_4 and A_5. Since 85 > 66, interchange 85 and 86 as follows:

32, 27, 51, 66, 85, 23, 13, 57

(e) Compare A_5 and A_6. Since 85 > 23, interchange 85 and 23 as follows:

32, 27, 51, 66, 23, 85, 13, 57

(f) Compare A_6 and A_7. Since 85 > 13, interchange 85 and 13 to yield:

32, 27, 51, 66, 23, 13, 85, 57

(g) Compare A_7 and A_8. Since 85 > 57, interchange 85 and 51 to yield:

32, 27, 51, 66, 23, 13, 57, 85

At the end of this first pass, the largest number, 85, has moved to the last position. However, the rest of the numbers are not sorted, even though some of them have changed their positions.

For the remainder of the passes, we show only the interchanges.

Pass 2. 27, 33, 51, 66, 23, 13, 57, 85
27, 33, 51, 23, 66, 13, 57, 85
27, 33, 51, 23, 13, 66, 57, 85
27, 33, 51, 23, 13, 57, 66, 85

At the end of Pass 2, the second largest number, 66, has moved its way down to the next-to-last position.

Pass 3. 27, 33, 23, 51, 13, 57, 66, 85
27, 33, 23, 13, 51, 57, 66, 85

Pass 4. 27, 23, 33, 13, 51, 57, 66, 85
27, 23, 13, 33, 51, 57, 66, 85

Pass 5. 23, 27, 13, 33, 51, 57, 66, 85
23, 13, 27, 33, 51, 57, 66, 85

Pass 6. 13, 23, 27, 33, 51, 57, 66, 85

Pass 6 actually has two comparisons, A_1 with A_2 and A_2 and A_3. The second comparison does not involve an interchange.

Pass 7. Finally, A_1 is compared with A_2. Since 13 < 23, no interchange takes place.

Since the list has 8 elements; it is sorted after the seventh pass.

<u>Complexity of the Bubble Sort Algorithm</u>

The time for a sorting algorithm is measured in terms of the number of comparisons f(n). There are *n* – 1 comparisons during the first pass, which places the largest element in the last position; there are *n* - 2 comparisons in the second step, which places the second largest element in the next-to-last position; and so on. Thus

$$f(n) = (n-1) + (n-2) + \dots + 2 + 1 = \frac{n(n-1)}{2} = \frac{n^2}{2} + O(n) = O(n^2)$$

<u>Searching</u>

- Let DATA be a collection of data elements in memory, and suppose a specific ITEM of information is given. ***Searching*** <u>refers to the operation of finding the location LOC of ITEM in DATA, or printing some message that ITEM does not appear there.</u>
- The search is said to be successful if ITEM does appear in DATA and unsuccessful otherwise.

Linear Search

Suppose DATA is a linear array with n elements. Given no other information about DATA, The way to search for a given ITEM in DATA is to compare ITEM with each element of DATA one by one. That is, first test whether DATA [l] = ITEM, and then test whether DATA[2] = ITEM, and so on. This method, which traverses DATA sequentially to locate ITEM, is called ***linear search or sequential search.***

Algorithm: (Linear Search) LINEAR (DATA, N, ITEM, LOC)

Here DATA is a linear array with N elements, and ITEM is a given item of information. This algorithm finds the location LOC of ITEM in DATA, or sets LOC: = 0 if the search is unsuccessful.

1. [Insert ITEM at the end of DATA.] Set DATA [N + 1]: = ITEM.
2. [Initialize counter.] Set LOC: = l.
3. [Search for ITEM.]
   Repeat while DATA [LOC] ≠ ITEM:
       Set LOC:= LOC + 1.
   [End of loop.]
4. [Successful?] If LOC = N + 1, then: Set LOC:= 0
5. Exit.

Complexity of the Linear Search Algorithm

Worst Case: The worst case occurs when one must search through the entire array DATA, i.e., when ITEM does not appear in DATA. In this case, the algorithm requires comparisons.

$$f(n) = n + 1$$

Thus, in the worst case, the running time is proportional to n.

Average Case: The average number of comparisons required to find the location of ITEM is approximately equal to half the number of elements in the array.

$$f(n) = \frac{n + 1}{2}$$

Binary Search

Suppose DATA is an array which is sorted in increasing numerical order or, equivalently, alphabetically. Then there is an extremely efficient searching algorithm, called *binary search*, which can be used to find the location LOC of a given ITEM of information in DATA.

Algorithm: (Binary Search) BINARY (DATA, LB, UB, ITEM, LOC)

Here DATA is a sorted array with lower bound LB and upper bound UB, and ITEM is a given item of information. The variables BEG, END and MID denote, the beginning, end and middle locations of a segment of elements of DATA.

This algorithm finds the location LOC of ITEM in DATA or sets LOC = NULL.

1. [Initialize segment variables.]
   Set BEG: = LB, END := UB and MID = INT((BEG + END)/2).
2. Repeat Steps 3 and 4 while BEG $\leq$ END and DATA [MID] $\neq$ ITEM.
3. If ITEM < DATA [MID], then:
   Set END := MID - 1.
   Else:
   Set BEG := MID + 1.
   [End of If structure.]
4. Set MID := INT((BEG + END)/2). [End of Step 2 loop.]
5. If DATA[MID] = ITEM, then:
   Set LOC := MID.
   Else:
   Set LOC := NULL.
   [End of If structure.]
6. Exit.

Remark: Whenever ITEM does

Complexity of the Binary Search Algorithm

The complexity is measured by the number *f(n)* of comparisons to locate ITEM in DATA where DATA contains *n* elements. Observe that each comparison reduces the sample size in half. Hence we require at most *f(n)* comparisons to locate ITEM where

$$2^{f(n)} > n \text{ or equivalently } f(n) = [\log_2 n] + 1$$

That is, the running time for the worst case is approximately equal to $\log_2 n$. One can also show that the running time for the average case is approximately equal to the running time for the worst case.

Dynamic Arrays

Dynamic array is an array whose size can be detem1ined at run time. In addition, it is also possible to change the size of a dynamic array at run time

MULTIDIMENSIONAL ARRAY

Two-Dimensional Arrays

A two-dimensional m x n array A is a collection of *m . n* data elements such that each element is specified by a pair of integers (such as J, K), called subscripts, with the property that

$$1 \leq J \leq m \text{ and } 1 \leq K \leq n$$

The element of A with first subscript j and second subscript k will be denoted by

$$A_{J,K} \text{ or } A[J, K]$$

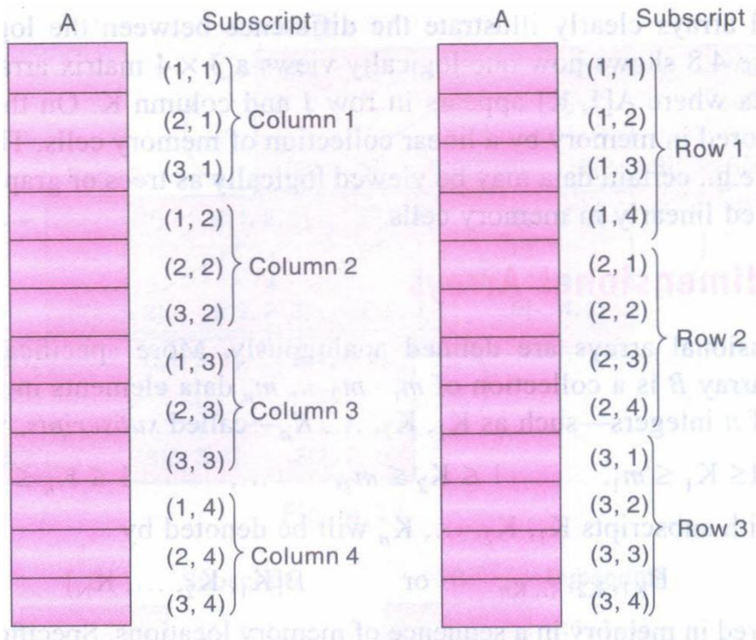
Two-dimensional arrays are called ***matrices*** in mathematics and ***tables*** in business applications.
There is a standard way of drawing a two-dimensional m x n array A where the elements of A form a rectangular array with *m rows* and *n columns* and where the element A[J, K] appears in *row J and column K.*

$$\begin{array}{cc} & \text{Columns} \\ & \begin{array}{cccc} 1 & 2 & 3 & 4 \end{array} \\ \text{Rows} \begin{array}{c} 1 \\ 2 \\ 3 \end{array} & \begin{bmatrix} A[1,1] & A[1,2] & A[1,3] & A[1,4] \\ A[2,1] & A[2,2] & A[2,3] & A[2,4] \\ A[3,1] & A[3,2] & A[3,3] & A[3,4] \end{bmatrix} \end{array}$$

Fig. *Two-Dimensional 3 × 4 Array A*

Representation of Two-Dimensional Arrays in Memory

Let A be a two-dimensional *m* x *n* array. Although A is pictured as a rectangular array of elements with *m* rows and *n* columns, the array will be represented in memory by a block of *m . n* sequential memory locations.
The programming language will store the array A either (1) column by column, is called ***column-major order*, or (2) row by row, in *row-major order***.



(a) Column-major order (b) Row-major order

The computer uses the formula to find the address of LA[K] in time independent of K.

$$LOC(LA[K]) = Base(LA) + w(K - 1)$$

The computer keeps track of *Base(A)-the* address of the first element A[1, 1] of A-and computes the address LOC(A[J, K]) of A[J, K] using the formula

(Column-major order) $LOC(A[J, K]) = Base(A) + w[M(K - 1) + (J - 1)]$

(Row-major order) $LOC(A[J, K]) = Base(A) + w[N(J - 1) + (K - 1)]$

<u>General Multidimensional Arrays</u>

An n-dimensional m_1 X m_2 X ... X m_n array B is a collection of m_1, m_2 ... m_n data elements in which each element is specified by a list of n integers-such as K_1 K_2 ... , K_n called subscripts, with the property that

$$1 \leq K_1 \leq m_1 , 1 \leq K_2 \leq m_2 \ldots\ldots 1 \leq K_n \leq m_n$$

The element of *B* with subscripts K_1 K_2 ... , K_n will be denoted by $B[K_1 K_2 \ldots , K_n]$
The programming language will store the array *B* either in row-major order or in column-major order.

Let C be such an n-dimensional array. The index set for each dimension of C consists of the consecutive integers from the lower bound to the upper bound of the dimension. The length L_i of dimension *i* of C is the number of elements in the index set, and L_i can be calculated, as

$$L_i = \text{upper bound} - \text{lower bound} + 1$$

For a given subscript K_i, the effective index E_i of L_i is the number of indices preceding K_i in the index set, and E_i can be calculated from

$$E_i = K_i - \text{lower bound}$$

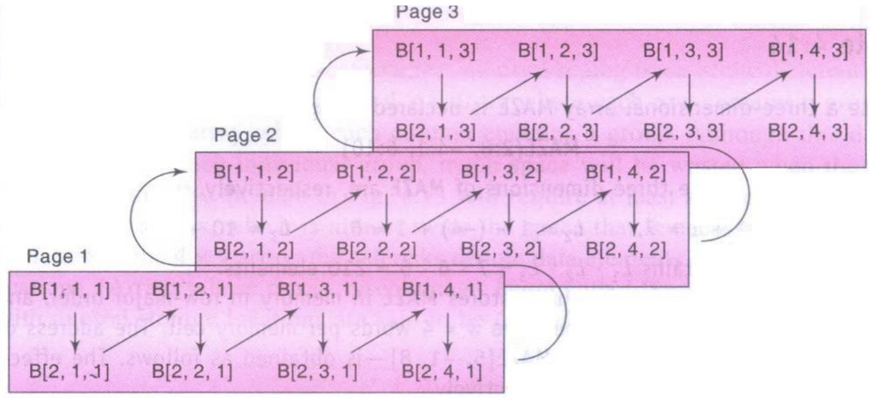
Then the address $LOC(C[K_1 K_2 \ldots , K_n]$ of an arbitrary element of C can be obtained from the formula

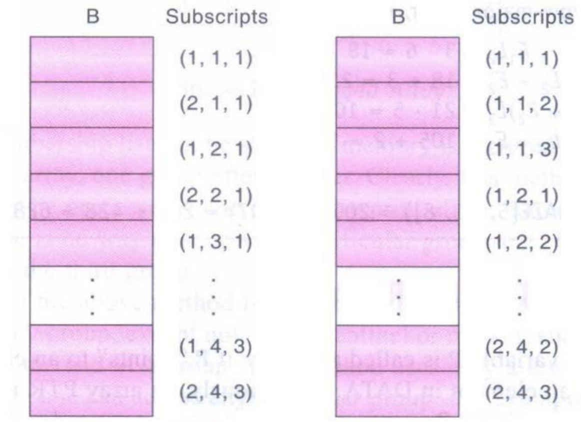
$$Base(C) + w[(((\ldots (E_N L_{N-1}] + E_{N-1}])L_{N-2}) + \ldots + E_3))L_2 + E_2)L_1 + E_1]$$

or from the formula

$$Base(C) + w[(\ldots ((E_1 L_2 + E2)L_3 + E_3)L_4 + \ldots + E_{N-1})L_N + E_N]$$

according to whether C is stored in column-major or row-major order.





(a) Column-major order (b) Row-major order

POLYNOMIALS

<u>What is a polynomial?</u>

"A polynomial is a sum of terms, where each term has a form ax^e, where **x** is the variable, **a** is the coefficient and **e** is the exponent."

Two example polynomials are:

$A(x) = 3x^{20} + 2x^5 + 4$

$B(x) = x^4 + 10x^3 + 3x^2 + 1$

The largest (or leading) exponent of a polynomial is called its degree.

Coefficients that are zero are not displayed.

The term with exponent equal to zero does not show the variable since **x** raised to a power of zero is **1**.

Assume there are two polynomials,

$A(x) = \Sigma\, a_i x^i$ and $B(x) = \Sigma\, b_i x_i$

then:

$A(x) + B(x) = \Sigma\, (a_i + b_i)\, x_i$

$A(x) \mathbf{.} B(x) = \Sigma\, (a_i x_i \mathbf{.}\ \Sigma\, (b_j x_j))$

Polynomial Representation

1. One way to represent polynomials in C is to use **typedef** to create the type polynomial as below:

```
#define MAX-DEGREE  101                  /*Max degree of polynomial+1*/
typedef struct{
                int degree;
                float coef[MAX-DEGREE];
        } polynomial;
```

Now if **a** is a variable and is of type polynomial and n < MAX_DEGREE, the polynomial $A(x) = \Sigma a_i x_i$ would be represented as:

a.degree = n

a.coef[i] = a_{n-i} , $0 \leq i \leq n$

In this representation, the coefficients is stored in order of decreasing exponents, such that a**.**coef [i] is the coefficient of x^{n-i} provided a term with exponent n-i exists;
Otherwise, a**.**coef [i] =0. This representation leads to very simple algorithms for most of the operations, it wastes a lot of space.

2. To preserve space an alternate representation that uses only one global array, **terms** to store all polynomials.

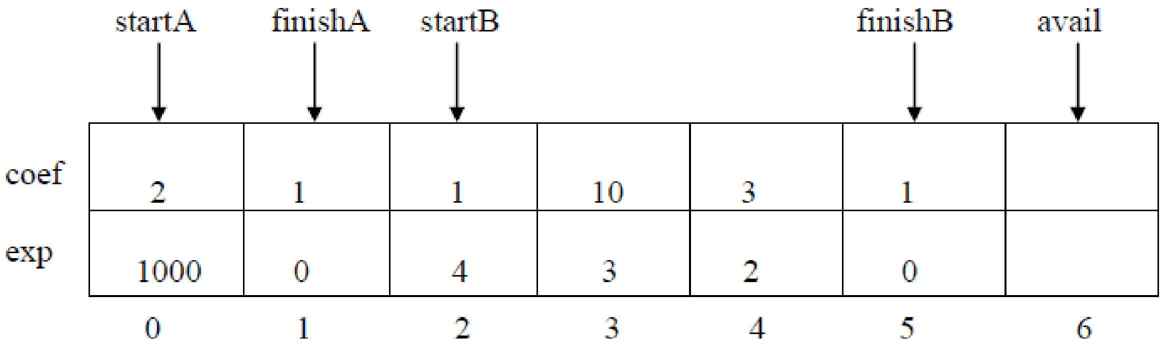
The C declarations needed are:

```
MAX_TERMS  100                  /*size of terms array*/
typedef struct{
                float coef;
                int expon;
        } polynomial;
polynomial terms[MAX-TERMS];
int avail = 0;
```

Consider the two polynomials

$A(x) = 2x^{l000} + 1$

$B(x) = x^4 + 10x^3 + 3x^2 + 1$



- The above figure shows how these polynomials are stored in the array terms. The index of the first term of A and B is given by startA and startB, while finishA and finishB give the index of the last term of A and B.
- The index of the next free location in the array is given by avail.
- For above example, startA=0, finishA=1, startB=2, finishB=5, & avail=6.

Polynomial Addition

- C function is written that adds two polynomials, A and B to obtain D =A + B.
- To produce D (x), **padd( )** is used to add A (x) and B (x) term by term. Starting at position avail, **attach( )** which places the terms of D into the array, ***terms***.
- If there is not enough space in terms to accommodate D, an error message is printed to the standard error device & exits the program with an error condition

---

```
void padd(int startA, int finishA, int startB, int finishB, int *startD,int *finishD)
{ /* add A(x) and B(x) to obtain D(x) */
    float coefficient;
    *startD = avail;
    while (startA <= finishA && startB <= finishB)
    switch(COMPARE(terms[startA].expon, terms[startB].expon))
    {
        case -1:            /* a expon < b expon */
            attach (terms [startB].coef, terms[startB].expon);
            startB++;
            break;

        case 0:             /* equal exponents */
            coefficient = terms[startA].coef + terms[startB].coef;

            if (coefficient)
                attach (coefficient, terms[startA].expon);
            startA++;
            startB++;
            break;
```

```
        case 1:                 /* a expon > b expon */
            attach (terms [startA].coef, terms[startA].expon);
            startA++;
    }

    /* add in remaining terms of A(x) */
    for(; startA <= finishA; startA++)
        attach (terms[startA].coef, terms[startA].expon);

    /* add in remaining terms of B(x) */
    for( ; startB <= finishB;  startB++)
        attach (terms[startB].coef, terms[startB].expon);
    *finishD = avail-i;
```

Function to add two polynomials

```
void attach(float coefficient, int exponent)
    {                           /* add a new term to the polynomial */
        if (avail >= MAX-TERMS)
        {
            fprintf(stderr,"Too many terms in the polynomial\n");
            exit(EXIT_FAILURE);
        }
        terms[avail].coef = coefficient;
        terms[avail++].expon = exponent;
    }
```

Function to add new term

Analysis of padd( ):

The number of non-zero terms in A and B is the most important factors in analyzing the time complexity.

Let **m** and **n** be the number of non-zero terms in A and B, If m >0 and n > 0, the **while** loop is entered. Each iteration of the loop requires O(1) time. At each iteration, the value of startA or startB or both is incremented. The iteration terminates when either startA or startB exceeds finishA or finishB.

The number of iterations is bounded by **m + n -1**

$$A(x) = \sum_{i=0}^{n} x^{2i} \quad \text{and} \quad B(x) = \sum_{i=0}^{n} x^{2i+1}$$

The time for the remaining two **for** loops is bounded by O(n + m) because we cannot iterate the first loop more than m times and the second more than n times. So, the asymptotic computing time of this algorithm is O(n +m).

SPARSE MATRICES

A matrix contains **m rows** and **n columns** of elements as illustrated in below figures. In this figure, the elements are numbers. The first matrix has five rows and three columns and the second has six rows and six columns. We write m x n (read "m by n") to designate a matrix with m rows and n columns. The total number of elements in such a matrix is **mn**. If **m** equals **n**, the matrix is square.

$$\begin{array}{c} \\ \textbf{row 0} \\ \textbf{row 1} \\ \textbf{row 2} \\ \textbf{row 3} \\ \textbf{row 4} \end{array}
\begin{array}{c} \begin{array}{ccc} \textbf{col0} & \textbf{col1} & \textbf{col2} \end{array} \\ \begin{bmatrix} -27 & 3 & 4 \\ 6 & 82 & -2 \\ 109 & -64 & 11 \\ 12 & 8 & 9 \\ 48 & 27 & 47 \end{bmatrix} \end{array}$$

Figure A

$$\begin{array}{c} \\ \textbf{row0} \\ \textbf{row1} \\ \textbf{row2} \\ \textbf{row3} \\ \textbf{row4} \\ \textbf{row5} \end{array}
\begin{array}{c} \begin{array}{cccccc} \textbf{col0} & \textbf{col1} & \textbf{col2} & \textbf{col3} & \textbf{col4} & \textbf{col 5} \end{array} \\ \begin{bmatrix} 15 & 0 & 0 & 22 & 0 & -15 \\ 0 & 11 & 3 & 0 & 0 & 0 \\ 0 & 0 & 0 & -6 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 91 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 28 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

Figure B

What is Sparse Matrix?

A matrix which contains many zero entries or very few non-zero entries is called as Sparse matrix.

In the **figure B** contains only 8 of 36 elements are nonzero and that is sparse.

Important Note:

A sparse matrix can be represented in 1-Dimension, 2- Dimension and 3- Dimensional array. When a sparse matrix is represented as a two-dimensional array as shown in **Figure B**, more space is wasted.

Example: consider the space requirements necessary to store a 1000 x 1000 matrix that has only 2000 non-zero elements. The corresponding two-dimensional array requires space for 1,000,000 elements. The better choice is by using a representation in which only the nonzero elements are stored.

Sparse Matrix Representation

- An element within a matrix can characterize by using the **triple <row,col,value>** This means that, an array of triples is used to represent a sparse matrix.
- Organize the triples so that the row indices are in ascending order.
- To perform any operation on a sparse matrix the following needs to be known
  - Number of rows
  - Number of columns
  - Number of nonzero elements

Implementation of the **Create** operation as below:

SparseMatrix Create(maxRow, maxCol) ::=

```
#define MAX_TERMS   101          /* maximum number of terms +1*/
typedef struct {
                    int   col;
                    int   row;
                    int value;
             } term;
term a[MAX_TERMS];
```

- The below figure shows the representation of matrix in the array **"a" a[0].row** contains the number of rows, **a[0].col** contains the number of columns and **a[0].value** contains the total number of nonzero entries.
- Positions 1 through 8 store the triples representing the nonzero entries. The row index is in the field row, the column index is in the field col, and the value is in the field value. The triples are ordered by row and within rows by columns.

a[0]	6	6	8
[1]	0	0	15
[2]	0	3	22
[3]	0	5	-15
[4]	1	1	11
[5]	1	2	3
[6]	2	3	-6
[7]	4	0	91
[8]	5	2	28

Fig (a): Sparse matrix stored as triple

Transposing a Sparse Matrix

Transpose of a matrix can be done by interchanging the rows and columns. This means each element a[i] [j] in the original matrix will become b[j] [i] in the transposed matrix

Direct interchanging of rows and columns is not correct in case of sparse •matrices because the ordering of rows and columns in the representation will be lost

a[0]	6	6	8
[1]	0	0	15
[2]	0	3	22
[3]	0	5	-15
[4]	1	1	11
[5]	1	2	3
[6]	2	3	-6
[7]	4	0	91
[8]	5	2	28

Fig (a): Sparse matrix stored as triple

b[0]	6	6	8
[1]	0	0	15
[2]	0	4	91
[3]	1	1	11
[4]	2	1	3
[5]	2	5	28
[6]	3	0	22
[7]	3	2	-6
[8]	5	0	-15

Fig (b): Transpose matrix stored as triple

Transposing a Matrix

To transpose a matrix, interchange the rows and columns. This means that each element **a[i][j]** in the original matrix becomes element **a[j][i]** in the transpose matrix.

A good algorithm for transposing a matrix:

```
for each row i
        take element <i, j, value> and store it as
        element <j, i, value> of the transpose;
```

If we process the original matrix by the **row indices** it is difficult to know exactly where to place element <j, i, value> in the transpose matrix until we processed all the elements that precede it.

This can be avoided by using the **column indices** to determine the placement of elements in the transpose matrix. This suggests the following algorithm:

```
for all elements in column j
        place element <i, j, value> in
        element <j, i, value>
```

The columns within each row of the transpose matrix will be arranged in ascending order.

```
void transpose (term a[], term b[])
{                    /* b is set to the transpose of a */
        int n, i, j, currentb;
        n = a[0].value;                /* total number of elements */
        b[0].row = a[0].col;           /* rows in b = columns in a */
        b[0].col = a[0].row;           /* columns in b = rows in a */
        b[0].value = n;
        if (n > 0)
```

```
{ currentb = 1;
        for (i = 0; i < a[0].col; i++)
                for (j= 1; j<=n; j++)
                        if (a[j].col  == i)
                        {
                                b[currentb].row = a[j].col;
                                b[currentb].col = a[j].row;
                                b[currentb].value  = a[j].value;
                                currentb++;
                        }
}
}
```

Transpose of a sparse matrix

STRING

BASIC TERMINOLOGY:

Each programming languages contains a character set that is used to communicate with the computer. The character set include the following:

Alphabet: A B C D E F G H I J K L M N O P Q R S T U V W X Y Z
Digits: 0 1 2 3 4 5 6 7 8 9
Special characters: + - / * ( ) , . $ = ' _ (Blank space)

String: A finite sequence S of zero or more Characters is called string.

Length: The number of characters in a string is called length of string.

Empty or Null String: The string with zero characters.

Concatenation: Let S_1 and S2 be the strings. The string consisting of the characters of S_1 followed by the character S_2 is called Concatenation of S_1 and S_2.

Ex: 'THE' // 'END' = 'THEEND'
'THE' // ' ' // 'END' = 'THE END'

Substring: A string Y is called substring of a string S if there exist string X and Z such that S = X // Y // Z
If X is an empty string, then Y is called an Initial substring of S, and Z is an empty string then Y is called a terminal substring of S.

Ex: 'BE OR NOT' is a substring of 'TO BE OR NOT TO BE'
'THE' is an initial substring of 'THE END'

STRINGS IN C

In C, the strings are represented as character arrays terminated with the null character \0.

Declaration 1:

```
#define MAX_SIZE  100              /* maximum size of string */
char s[MAX_SIZE]  = {"dog"};
char t[MAX_SIZE]  = {"house"};
```

s[0]	s[1]	s[2]	s[3]
d	o	g	\0

t[0]	t[1]	t[2]	t[3]	t[4]	t[5]
h	o	u	s	e	\0

The above figure shows how these strings would be represented internally in memory.

<u>Declaration 2:</u>

```
char s[ ] = {"dog"};
char t[ ] = {"house"};
```

Using these declarations, the C compiler will allocate just enough space to hold each word including the null character.

STORING STRINGS

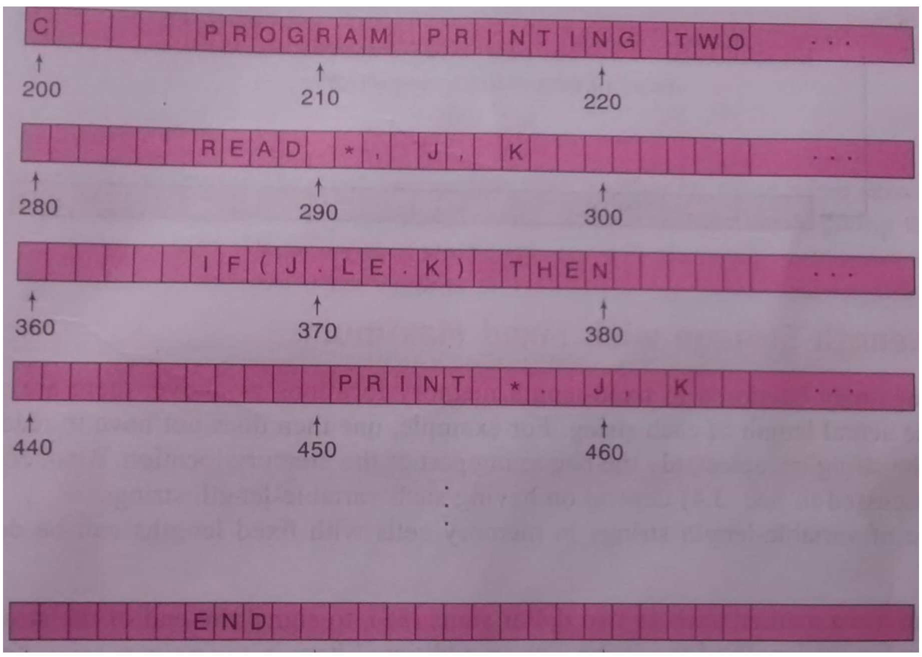
Strings are stored in three types of structures

1. Fixed length structures
2. Variable length structures with fixed maximum
3. Linked structures

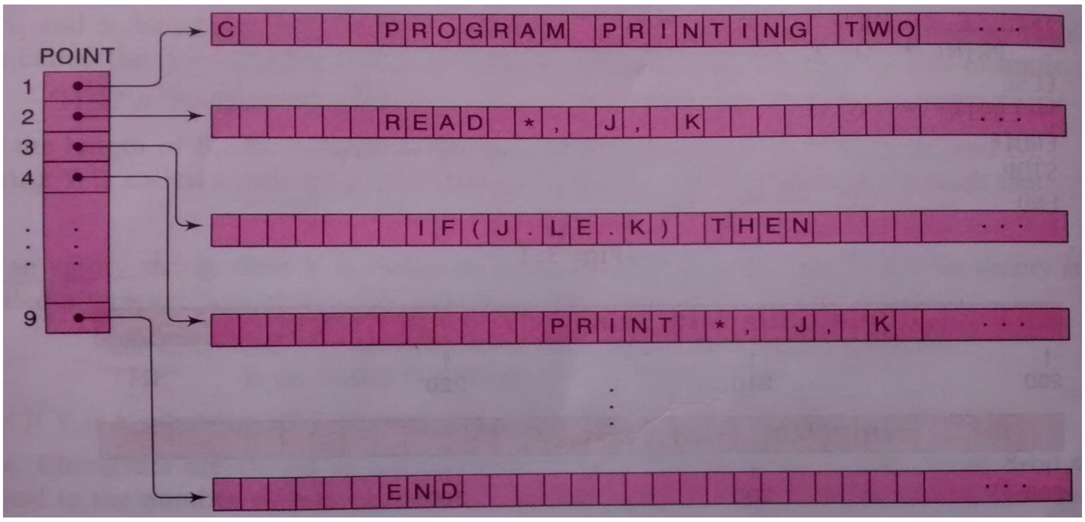
Record Oriented Fixed length storage:

In fixed length structures each line of print is viewed as a record, where all have the same length i.e., where each record accommodates the same number of characters.

Example: Suppose the input consists of the program. Using a record oriented, fixed length storage medium, the input data will appear in memory as pictured below.



Suppose, if new record needs to be inserted, then it requires that all succeeding records be moved to new memory location. This disadvantages can be easily remedied as shown in below figure.



That is, one can use a linear array POINT which gives the address of successive record, so that the records need not be stored in consecutive locations in memory. Inserting a new record will require only an updating of the array POINT.

<u>The main advantages of this method are</u>

1. The ease of accessing data from any given record
2. The ease of updating data in any given record (as long as the length of the new data does not exceed the record length)

<u>The main disadvantages are</u>

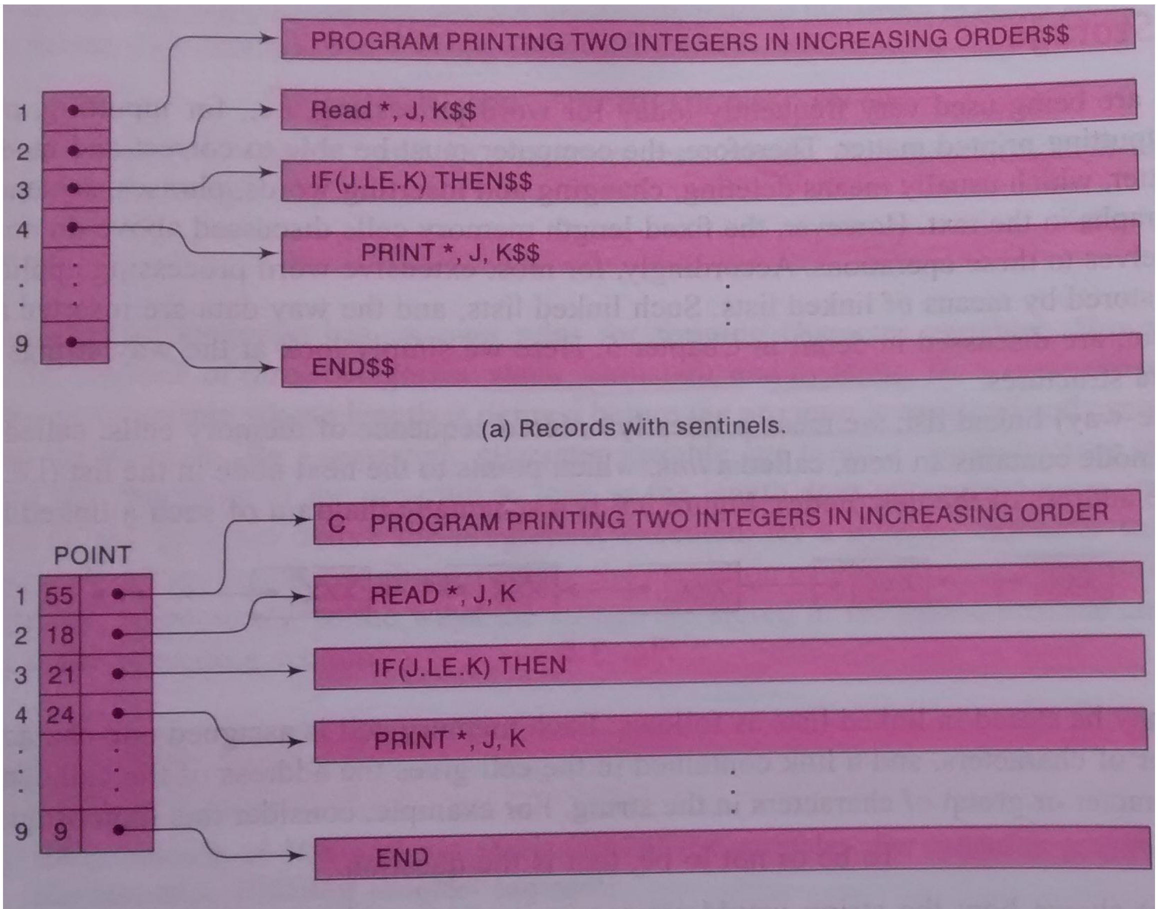
1. Time is wasted reading an entire record if most of the storage consists of inessential blank spaces.
2. Certain records may require more space than available
3. When the correction consists of more or fewer characters than the original text, changing a misspelled word requires record to be changed.

Variable length structures with fixed maximum

The storage of variable-length strings in memory cells with fixed lengths can be done in two general ways

1. One can use a marker, such as two dollar signs ($$), to signal the end of the string
2. One can list the length of the string—as an additional item in the pointer array

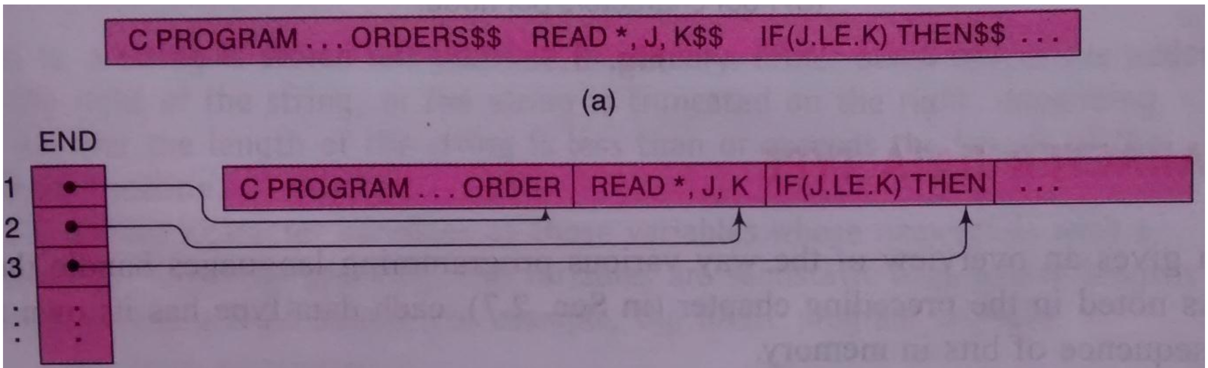
Example:



(a) Records with sentinels.

(b) Record whose lengths are listed.

The other method to store strings one after another by using some separation marker, such as the two dollar sign ($$) or by using a pointer giving the location of the string.



(a)

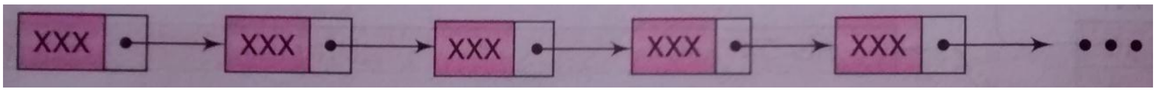
(b)

These ways of storing strings will save space and are sometimes used in seco ndary memory when records are relatively permanent and require little changes.
These types of methods of storage are usually inefficient when the strings and their lengths are frequently being changed.

Linked Storage

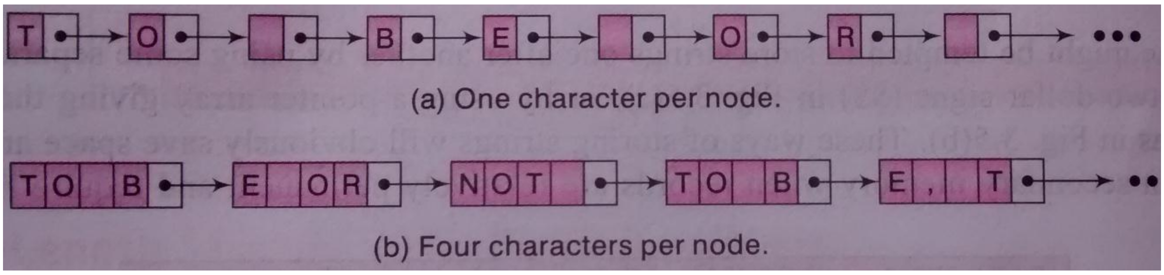
- Most extensive word processing applications, strings are stored by means of linked lists.

- In a one way linked list, a linearly ordered sequence of memory cells called nodes, where each node contains an item called a ***link*,** which points to the next node in the list, i.e., which consists the address of the next node.



Strings may be Stored in linked list as follows:
Each memory cell is assigned one character or a fixed number of characters and a link contained in the cell gives the address of the cell containing the next character or group of character in the string.

Ex: TO BE OR NOT TO BE



CHARACTER DATA TYPE

The various programming languages handles character data type in different ways.

Constants

Many programming languages denotes string constants by placing the string in either single or double quotation marks.

Ex: 'THE END'
"THE BEGINNING"

The string constants of length 7 and 13 characters respectively.

Variables

Each programming languages has its own rules for forming character variables. These variables fall into one of three categories

1. **Static:** In static character variable, whose length is defined before the program is executed and cannot change throughout the program
2. **Semi-static:** The length of the variable may vary during the execution of the program as long as the length does not exceed a maximum value determined by the program before the program is executed.
3. **Dynamic:** The length of the variable can change during the execution of the program.

STRING OPERATION

Substring

Accessing a substring from a given string requires three pieces of information:

(1) The name of the string or the string itself
(2) The position of the first character of the substring in the given string
(3) The length of the substring or the position of the last character of the substring.

Syntax: SUBSTRING (string, initial, length)

The syntax denote the substring of a string S beginning in a position K and having a length L.

Ex: SUBSTRING ('TO BE OR NOT TO BE', 4, 7) = 'BE OR N'
SUBSTRING ('THE END', 4, 4) = ' END'

Indexing

Indexing also called pattern matching, refers to finding the position where a string pattern P first appears in a given string text T. This operation is called INDEX

Syntax: INDEX (text, pattern)

If the pattern P does not appears in the text T, then INDEX is assigned the value 0.
The arguments "text" and "pattern" can be either string constant or string variable.

Concatenation

Let S_1 and S_2 be string. The concatenation of S_1 and S_2 which is denoted by S_1 // S_2, is the string consisting of the characters of S_1 followed by the character of S_2.
Ex:

(a) Suppose S_1 = 'MARK' and S_2= 'TWAIN' then
S_1 // S_2 = 'MARKTWAIN'

Concatenation is performed in C language using ***strcat*** function as shown below

strcat (S1, S2);

Concatenates string S1 and S2 and stores the result in S1
strcat ( ) function is part of the ***string.h*** header file; hence it must be included at the time of pre- processing

Length

The number of characters in a string is called its length.

Syntax: LENGTH (string)

Ex: LENGTH ('computer') = 8

String length is determined in C language using the ***strlen( )*** function, as shown below:

X = strlen ("sunrise");

strlen function returns an integer value 7 and assigns it to the variable X

Similar to ***strcat, strlen*** is also a part of string.h, hence the header file must be included at the time of pre-processing.

Function	Description
*char *strcat(char *dest, char *src)*	concatenate *dest* and *src* strings; return result in *dest*
*char *strncat(char *dest, char *src, int n)*	concatenate *dest* and *n* characters from *src*; return result in *dest*
*char *strcmp(char *str1, char *str2)*	compare two strings; return < 0 if *str1* < *str2*; 0 if *str1* = *str2*; > 0 if *str1* > *str2*
*char *strncmp(char *str1, char *str2, int n)*	compare first *n* characters return < 0 if *str1* < *str2*; 0 if *str1* = *str2*; > 1 if *str1* > *str2*
*char *strcpy(char *dest, char *src)*	copy *src* into *dest*; return *dest*
*char *strncpy(char *dest, char *src, int n)*	copy *n* characters from *src* string into *dest*; return *dest*;
*size_t strlen(char *s)*	return the length of a *s*
*char *strchr(char *s, int c)*	return pointer to the first occurrence of *c* in *s*; return *NULL* if not present
*char *strrchr(char *s, int c)*	return pointer to last occurrence of *c* in *s*; return *NULL* if not present
*char *strtok(char *s, char *delimiters)*	return a token from *s*; token is surrounded by *delimiters*
*char *strstr(char *s, char *pat)*	return pointer to start of *pat* in *s*
*size_t strspn(char *s, char *spanset)*	scan *s* for characters in *spanset*; return length of span
*size_t strcspn(char *s, char *spanset)*	scan *s* for characters not in *spanset*; return length of span
*char *strpbrk(char *s, char *spanset)*	scan *s* for characters in *spanset*; return pointer to first occurrence of a character from *spanset*

Figure 2.8: C string functions

PATTERN MATCHING ALGORITHMS

Pattern matching is the problem of deciding whether or not a given string pattern P appears in a string text T. The length of P does not exceed the length of T.

First Pattern Matching Algorithm

- The first pattern matching algorithm is one in which comparison is done by a given pattern P with each of the substrings of T, moving from left to right, until a match is found.

  $$W_K = \textbf{SUBSTRING (T, K, LENGTH (P))}$$

- Where, W_K denote the substring of T having the same length as P and beginning with the K^{th} character of T.
- First compare P, character by character, with the first substring, W_1. If all the characters are the same, then $P = W_1$ and so P appears in T and INDEX (T, P) = 1.
- Suppose it is found that some character of P is not the same as the corresponding character of W_1. Then $P \neq W_1$

- Immediately move on to the next substring, W_2 That is, compare P with W_2. If $P \neq W_2$ then compare P with W_3 and so on.
- The process stops, When P is matched with some substring W_K and so P appears in T and INDEX(T,P) = K or When all the W_K'S with no match and hence P does not appear in T.
- The maximum value MAX of the subscript K is equal to LENGTH(T) -LENGTH(P) +1.

Algorithm: (Pattern Matching)
P and T are strings with lengths R and S, and are stored as arrays with one character per element. This algorithm finds the INDEX of P in T.

1. [Initialize.] Set K: = 1 and MAX: = S - R + 1
2. Repeat Steps 3 to 5 while K ≤ MAX
3. Repeat for L = 1 to R: [Tests each character of P]
   If P[L] ≠ T[K + L – l], then: Go to Step 5
   [End of inner loop.]
4. [Success.] Set INDEX = K, and Exit
5. Set K := K + 1
   [End of Step 2 outer loop]
6. [Failure.] Set INDEX = O
7. Exit

<u>Observation of algorithms</u>

- P is an r-character string and T is an s-character string
- Algorithm contains two loops, one inside the other. The outer loop runs through each successive R-character substring W_K = T[K] T[K + 1] ... T[K+R-l] of T.
- The inner loop compares P with W_K, character by character. If any character does not match, then control transfers to Step 5, which increases K and then leads to the next substring of T.
- If all the R characters of P do match those of some W_K then P appears in T and K is the INDEX of P in T.
- If the outer loop completes all of its cycles, then P does not appear in T and so INDEX = 0.

<u>Complexity</u>

The complexity of this pattern matching algorithm is equal to $O(n^2)$

<u>Second Pattern Matching Algorithm</u>

The second pattern matching algorithm uses a table which is derived from a particular pattern P but is independent of the text T.
For definiteness, suppose

P = aaba

This algorithm contains the table that is used for the pattern P = *aaba*.

<u>The table is obtained as follows.</u>

- Let Qi denote the initial substring of *P* of length *i*, hence Q0 = A, Q1 = *a*, Q2 = *a2*, Q3 = *aab*, Q4 = *aaba* = *P* (Here Q0 = A is the empty string.)
- The rows of the table are labeled by these initial substrings of *P*, excluding *P* itself.
- The columns of the table are labeled *a*, *b* and *x*, where *x* represents any character that doesn't appear in the pattern *P*.
- Let f be the function determined by the table; i.e., let *f(Qi, t)* denote the entry in the table in row Qi and column *t* (where *t* is any character). This entry *f*(Q_i, *t*) is defined to be the largest Q that appears as a terminal substring in the string (Q_i *t*) the concatenation of Qi and *t*.

For example,

a2 is the largest Q that is a terminal substring of *Q2a* = a^3, so *f(Q2, a)* = Q2

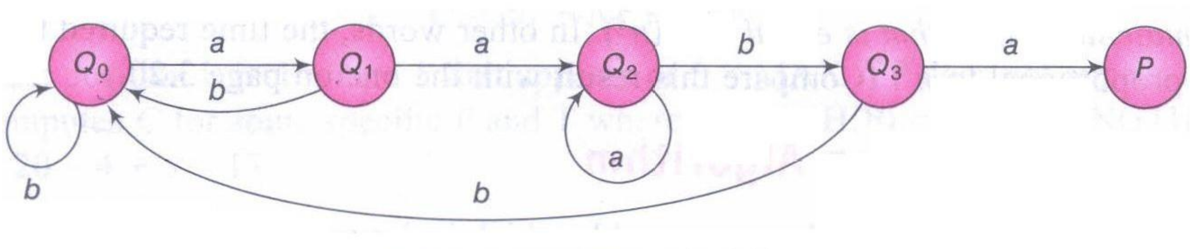
A is the largest Q that is a terminal substring of Q1*b* = *ab*, so *f(Q1, b)* = Q0

a is the largest Q that is a terminal substring of *Q0a* = *a*, so *f(Q0, a)* = Q1

A is the largest Q that is a terminal substring of *Q3a* = a^3bx, so *f(Q3, x)* = Q0

	a	b	x
Q_0	Q_1	Q_0	Q_0
Q_1	Q_2	Q_0	Q_0
Q_2	Q_2	Q_3	Q_0
Q_3	P	Q_0	Q_0

(a) Pattern matching table



b Pattern matching graph

Although Q1 = *a* is a terminal substring of *Q2a* = a^3, we have *f(Q2, a)* = Q2 because Q2 is also a terminal substring of *Q2a* = a^3 and Q2 is larger than *Q1*. We note *that f(Qi, x)* = Q0 for any *Q*, since *x* does not appear in the pattern *P* Accordingly, the column corresponding to *x* is usually omitted from the table.

<u>Pattern matching Graph</u>

The graph is obtained with the table as follows.

First, a node in the graph corresponding to each initial substring Qi of *P*. The Q's are called the *states* of the system, and Q0 is called the *initial* state.

Second, there is an arrow (a directed edge) in the graph corresponding to each entry in the table. Specifically, if

$$f(Q_i,\ t) = Q_j$$

then there is an arrow labeled by the character *t* from *Qi* to *Qj*

For example, f(Q2, *b) = Q3* so there is an arrow labeled *b* from Q2 to *Q3*
For notational convenience, all arrows labeled *x* are omitted, which must lead to the initial state *Qo*.

The second pattern matching algorithm for the pattern P = *aaba.*

- Let T = T1 T2 T3 ... TN denote the n-character-string text which is searched for the pattern P. Beginning with the initial state Q0 and using the text T, we will obtain a sequence of states S1, S2, S3, ... as follows.
- Let S1 = Q0 and read the first character T1. The pair (S1, T1) yields a second state S2; that is, F(S1, T1) = S2, Read the next character T2, The pair (S2, T2) yields a state S3, and so on.

There are two possibilities:

1. Some state SK = P, the desired pattern. In this case, P does appear in T and its index is K - LENGTH(P).
2. No state S1, S2, ... , SN +1 is equal to P. In this case, P does not appear in T.

Algorithm: (PATTERN MATCHING) The pattern matching table $F(Q_1, T)$ of a pattern P is in memory, and the input is an N-character string $T = T_1\ T_2\ T_3 \ldots\ldots T_N$. The algorithm finds the INDEX of P in T.

1. [Initialize] set K: =1 ans $S_1 = Q_0$
2. Repeat steps 3 to 5 while $S_K \neq P$ and $K \leq N$
3. Read T_K
4. Set S_{K+1} : = $F(S_K,\ T_K)$ [finds next state]
5. Set K: = K + 1 [Updates counter]
   [End of step 2 loop]
6. [Successful ?]
   If $S_K = P$, then
   INDEX = K – LENGTH (P)
   Else
   INDEX = 0
   [End of IF structure]
7. Exit.

Programs:

1.Swapping of two numbers

```
 #include <stdio.h>
 void swap(int*, int*); //Swap function declaration
 int main()
{
   int x, y;
    printf("Enter the value of x and y\n");
   scanf("%d%d",&x,&y);
    printf("Before Swapping\nx = %d\ny = %d\n", x, y);
    swap(&x, &y);
    printf("After Swapping\nx = %d\ny = %d\n", x, y);
    return 0;
}
//Swap function definition
void swap(int *a, int *b)
{
   int t;
    t  = *b;
   *b = *a;
   *a = t;
}
Note:
```

- If 'X' and ‘Y' are passed by value, then the effect of swapping will not be seen in the main function. The variables ‘x' and 'y' will retain their values.
- When only one value needs to be sent from the called function to the calling function, we can use the 'return' statement.
- When more than one value needs to be sent from the called function to the calling function, we have to use call by reference

2.Function pointer

```
int sum (int num1, int num2)
{
   return num1+num2;
}
int main()
{    int op1, op2;
   int (*f2p) (int, int);
   f2p = sum;
    //Calling function using function pointer
    op1 = f2p(10, 13);

    //Calling function in normal way using function name
    op2 = sum(10, 13);

   printf("Output1: Call using function pointer: %d",op1);
   printf("\nOutput2: Call using function name: %d", op2);

   return 0;
}
```

Output:

Output1: Call using function pointer: 23
Output2: Call using function name: 23

Note: You can even remove the ampersand from this statement because a function name alone represents the function address. This means the above statement can also be written like this:

```
void (*fun_ptr)(int) = fun;
```

Program to find the sum of all elements in an array using pointers

```
#include <stdio.h>
#include <malloc.h>
 void main()
{
    int i, n, sum = 0;
    int *a;
                printf("Enter the size of array A \n");
                scanf("%d", &n);
       a = (int *) malloc(n * sizeof(int));
       printf("Enter Elements of First List \n");
    for (i = 0; i < n; i++)
      {
                scanf("%d", a + i);
    }
       </*  Compute the sum of all elements in the given array */
       for (i = 0; i < n; i++)
      {
                sum = sum + *(a + i);
    }
       printf("Sum of all elements in array = %d\n", sum);
 }
```

Output
Enter the size of array A
5
Enter Elements of First List
4
9
10
56
100
`Sum of all elements in array = 179`

Program to read and print an array of 'm X n matrix using dynamic arrays

```
#include<stdio.h>
#include<stdlib.h>
int main()
{
        int m, n;
        printf("Enter no. of rows and columns: ");
        scanf("%d%d", &m, &n);
        int **a;
        //Allocate memory to matrix
        a = (int **) malloc(m * sizeof(int *));
        for(int i=0; i<m; i++)
        {
                a[i] = (int *) malloc(n * sizeof(int));
        }
        //Read elements into matrix
        printf("Enter matrix elements: ");
        for(int i=0; i<m; i++)
        {
                for(int j=0; j<n; j++)
                {
                        scanf("%d", &a[i][j]);
                }
        }
        //Print elements in the matrix
        printf("Matrix elements are: \n");
```

```
        for(int i=0; i<m; i++)
        {
                for(int j=0; j<n; j++)
                {
                        printf("%d ", a[i][j]);
                }
                printf("\n");
        }
        //Dellocating memory of matrix
        for(int i=0; i<m; i++)
        {
                free(a[i]);
        }
        free(a);
        return 0;
}
```

Output

Enter no. of rows and columns: 3 3
Enter matrix elements:
1 2 3
4 5 6
7 8 9
Matrix elements are:
1 2 3
4 5 6
7 8 9

Bubble sort

```
/*PROGRAM FOR BUBBLE SORTING */
#include <stdio.h>
#include <stdlib.h>
#define N 100
main()
{
  int array[N],n,i,j,temp;
  /* Read number of elements in array */
  printf("ENTER NUMBER OF ELEMENTS:");
  scanf("%d",&n);
/* Read the elements of array */
  printf("ENTER %d ELEMENTS\n",n);
for(i=0;i<n;i++)
{
  scanf("%d",&array[i]); }
/* Do Bubble Sort */
  for(i=0;i<(n-1);i++)
  {
    for(j=0;j<(n-i-1);j++)
    {
      if(array[j]>array[j+1])
      {
        temp = array[j];
        array[j]=array[j+1];
        array[j+1] = temp;
      }
    }
  }
/* Print the Sorted Array */
printf("______________________________________________\n");
printf("Sorted list in Ascending Order:\n");
for(i=0;i<n;i++)
{
  printf("%d\t",array[i]);
}
printf("\n______________________________________________\n");
  getch();
  return 0;
}
```

Linear Search program

```
#include <stdio.h>
 int main()
{
  int array[100], search, c, n;

  printf("Enter number of elements in array\n");
  scanf("%d", &n);

  printf("Enter %d integer(s)\n", n);

  for (c = 0; c < n; c++)
    scanf("%d", &array[c]);

  printf("Enter a number to search\n");
  scanf("%d", &search);
   for (c = 0; c < n; c++)
  {
    if (array[c] == search)    /* If required element is found */
    {
      printf("%d is present at location %d.\n", search, c+1);
      break;
    }
  }
  if (c == n)
    printf("%d isn't present in the array.\n", search);

  return 0;
}
```

Binary Search

```
#include <stdio.h>
 int main()
{
   int c, first, last, middle, n, search, array[100];
    printf("Enter number of elements\n");
   scanf("%d",&n);
    printf("Enter %d integers\n", n);
    for (c = 0; c < n; c++)
      scanf("%d",&array[c]);
    printf("Enter value to find\n");
   scanf("%d", &search);
    first = 0;
   last = n - 1;
   middle = (first+last)/2;
    while (first <= last) {
      if (array[middle] < search)
         first = middle + 1;
      else if (array[middle] == search) {
         printf("%d found at location %d.\n", search, middle+1);
         break;
      }
      else
         last = middle - 1;
       middle = (first + last)/2;
   }
   if (first > last)
      printf("Not found! %d isn't present in the list.\n", search);
    return 0;
}
```

Write a 'C' program to merge two sorted array elements into-a single sorted array

```
#include <stdio.h>
void main()
{
    int array1[50], array2[50], array3[100], m, n, i, j, k = 0;
    printf("\n Enter size of array Array 1: ");
    scanf("%d", &m);
    printf("\n Enter sorted elements of array 1: \n");
    for (i = 0; i < m; i++)
    {
        scanf("%d", &array1[i]);
    }
    printf("\n Enter size of array 2: ");
    scanf("%d", &n);
    printf("\n Enter sorted elements of array 2: \n");
    for (i = 0; i < n; i++)
    {
        scanf("%d", &array2[i]);
    }
    i = 0;
    j = 0;
/* Merging Starts*/
    while (i < m && j < n)
    {
        if (array1[i] < array2[j])
        {
            array3[k] = array1[i];
            i++;
        }
        else
        {
            array3[k] = array2[j];
            j++;
        }
        k++;
    }
    if (i >= m)
    {
        while (j < n)
        {
            array3[k] = array2[j];
            j++;
            k++;
        }
    }
    if (j >= n)
    {
        while (i < m)
        {
            array3[k] = array1[i];
            i++;
            k++;
        }
    }
    printf("\n After merging: \n");
    for (i = 0; i < m + n; i++)
    {
        printf("\n%d", array3[i]);
    }

}
```

Assignment: Redo the program to avoid duplicate elements

Program to read and print elements using Dynamic Arrays

```
#include <stdio.h>
#include <stdlib.h>

int main()
{
   int i, max;
   int *ptr;

   // Input maximum elements of array
   printf("Enter total number of elements: ");
   scanf("%d", &max);

   // Allocate memory for 'max' integer elements
   ptr = (int *) malloc(max * sizeof(int));

   // If memory not allocated
   if(ptr == NULL)
   {
      printf("Memory is not created!!!");
      exit(0); // Exit from the program
   }

   // Input elements from user
   printf("Enter %d elements: \n", max);
   for (i = 0; i < max; i++)
      scanf("%d", (ptr + i));

   // Print all elements
   printf("\nArray elements are:\n");
   for (i = 0; i < max; i++)
      printf("%d ", *(ptr + i));

   // Release allocated memory
   free(ptr);
    return 0;
}
```

Program to maximum of n elements using dynamic arrays

```
#include <stdio.h>
#include <stdlib.h>
int main()
{
   int i, num;
   float *data;
   printf("Enter total number of elements(1 to 100): ");
   scanf("%d", &num);

   // Allocates the memory for 'num' elements.
   data = (float*) calloc(num, sizeof(float));

   if(data == NULL)
   {
      printf("Error!!! memory not allocated.");
      exit(0);
   }

   printf("\n");

   // Stores the number entered by the user.
   for(i = 0; i < num; ++i)
   {
      printf("Enter Number %d: ", i + 1);
      scanf("%f", data + i);
   }
```

```

    // Loop to store largest number at address data
    for(i = 1; i < num; ++i)
    {
       // Change < to > if you want to find the smallest number
       if(*data < *(data + i))
           *data = *(data + i);
    }
    printf("Largest element = %.2f", *data);
    return 0;
}
```

Output

```
Enter total number of elements(1 to 100): 10

Enter Number 1: 2.34
Enter Number 2: 3.43
Enter Number 3: 6.78
Enter Number 4: 2.45
Enter Number 5: 7.64
Enter Number 6: 9.05
Enter Number 7: -3.45
Enter Number 8: -9.99
Enter Number 9: 5.67
Enter Number 10: 34.95
Largest element: 34.95
```

Program to calculate the sum of positive/negative numbers using dynamic arrays

```
#include<stdio.h>
int main()
{
int total, I,positiveSum = 0,negativeSum = 0, *numbers;
printf("How many numbers you want to add : ");
scanf("%d",&total);
numbers=(int *) malloc(total* sizeof(int))
for(i=0; i<total; i++){
printf("Enter number %d : ",(i+1));
scanf("%d",numbers+i);
}
for(i=0 ; i<total ; i++)
{
if(*(numbers+i) < 0)
{
negativeSum += numbers+i;
}else
{
positiveSum += numbers+i;
}
}
printf("You have entered : \n");
for(i=0 ; i<total; i++){
printf("%d ",numbers+i);
}
printf("\nPositive numbers sum : %d",positiveSum);
printf("\nNegative numbers sum : %d\n",negativeSum);
}
```

Program for Finding Transpose of a Sparse Matrix

```
struct sparsematrix
{
};
int row;
int col;
int value;
};

typedef struct sparsematrix MATRIX;
// Function to find the transpose of a sparse matrix
void transpose(MA TRIX a[ ], MATRIX b[ ])
{
int n;
int i,j,k;
b[0].row = a[0].col;        // rows in b = cols in a
b[0].col = a[0].row:        // cols in b =rows in a
b[0].value = a[0].value;  // number of elements in b =number of elements in a
n = a[0].value;             // total number of elements
if(n>0)                     // nonzero matrix
{
k= 1;                                 // position to put the next transposed triple in b
for(i=0; i<a[0].col; i+ +)
{
for(j=1; j<= r: j++)
{
if(a[j].col = = i)
            {
            b[k].row = a[j].col;
            b[k].col = a[j].row; _
            b[k].value = a[j].value;
            k++;

            }
          }
      }
  }
}
```

Program to add two Polynomials usmg Arrays

```
/* program for addition of two polynomials
 * polynomial are stored using structure
 * and program uses array of structure
 */
 #include<stdio.h>

 /* declare structure for polynomial */
 struct poly
 {
                int coeff;
                int expo;
 };
 /* declare three arrays p1, p2, p3 of type structure poly.
 * each polynomial can have maximum of ten terms
 * addition result of p1 and p2 is stored in p3 */

 struct poly p1[10],p2[10],p3[10];
```

```c
/* function prototypes */
int readPoly(struct poly []);
int addPoly(struct poly [],struct poly [],int ,int ,struct poly []);
void displayPoly( struct poly [],int terms);

int main()
{
		int t1,t2,t3;

		/* read and display first polynomial */
		t1=readPoly(p1);
		printf(" \n First polynomial : ");
		displayPoly(p1,t1);
		/* read and display second polynomial */
		t2=readPoly(p2);
		printf(" \n Second polynomial : ");
		displayPoly(p2,t2);

		/* add two polynomials and display resultant polynomial */
		t3=addPoly(p1,p2,t1,t2,p3);
		printf(" \n\n Resultant polynomial after addition : ");
		displayPoly(p3,t3);
		printf("\n");

		return 0;
}

int readPoly(struct poly p[10])
{
		int t1,i;

		printf("\n\n Enter the total number of terms in the polynomial:");
		scanf("%d",&t1);

		printf("\n Enter the COEFFICIENT and EXPONENT in DESCENDING ORDER\n");
		for(i=0;i<t1;i++)
		{
				printf("   Enter the Coefficient(%d): ",i+1);
				scanf("%d",&p[i].coeff);
				printf("      Enter the exponent(%d): ",i+1);
				scanf("%d",&p[i].expo);       /* only statement in loop */
		}
		return(t1);
}

int addPoly(struct poly p1[10],struct poly p2[10],int t1,int t2,struct poly p3[10])
{
		int i,j,k;


		i=0;
		j=0;
		k=0;

		while(i<t1 && j<t2)
		{
				if(p1[i].expo==p2[j].expo)
				{
						p3[k].coeff=p1[i].coeff + p2[j].coeff;
						p3[k].expo=p1[i].expo;

						i++;
						j++;
						k++;
				}
```

```c
                else if(p1[i].expo>p2[j].expo)
                {
                        p3[k].coeff=p1[i].coeff;
                        p3[k].expo=p1[i].expo;
                        i++;
                        k++;
                }
                else
                {
                        p3[k].coeff=p2[j].coeff;
                        p3[k].expo=p2[j].expo;
                        j++;
                        k++;
                }
        }

        /* for rest over terms of polynomial 1 */
        while(i<t1)
        {
                p3[k].coeff=p1[i].coeff;
                p3[k].expo=p1[i].expo;
                i++;
                k++;
        }
        /* for rest over terms of polynomial 2 */
        while(j<t2)
        {
                p3[k].coeff=p2[j].coeff;
                p3[k].expo=p2[j].expo;
                j++;
                k++;
        }

        return(k); /* k is number of terms in resultant polynomial*/
}

void displayPoly(struct poly p[10],int term)
{
        int k;

        for(k=0;k<term-1;k++)
        printf("%d(x^%d)+",p[k].coeff,p[k].expo);
        printf("%d(x^%d)",p[term-1].coeff,p[term-1].expo);
}
```

Output

Enter the total number of terms in the polynomial:4
Enter the COEFFICIENT and EXPONENT in DESCENDING ORDER
Enter the Coefficient(1): 3
Enter the exponent(1): 4
Enter the Coefficient(2): 7
Enter the exponent(2): 3
Enter the Coefficient(3): 5
Enter the exponent(3): 1
Enter the Coefficient(4): 8
Enter the exponent(4): 0

First polynomial : 3(x^4)+7(x^3)+5(x^1)+8(x^0)

Enter the total number of terms in the polynomial:5
Enter the COEFFICIENT and EXPONENT in DESCENDING ORDER
Enter the Coefficient(1): 7
Enter the exponent(1): 5
Enter the Coefficient(2): 6
Enter the exponent(2): 4

Enter the Coefficient(3): 8
Enter the exponent(3): 2
Enter the Coefficient(4): 9
Enter the exponent(4): 1
Enter the Coefficient(5): 2
Enter the exponent(5): 0
Second polynomial : 7(x^5)+6(x^4)+8(x^2)+9(x^1)+2(x^0)

Resultant polynomial after addition : 7(x^5)+9(x^4)+7(x^3)+8(x^2)+14(x^1)+10(x^0)