CHAPTER 4

Arrays, Records and Pointer

Introduction

- Array: Array is one kind of linear structure where the linear relationship between elements are maintained by means of Sequential memory location.
- Operations performed on any linear structure(Array or linked list) are as follows:
    - Traversal: Processing every element.
    - Search: Finding the location of the element with a given search parameter such a value or a key.
    - Insertion: Adding a new element to the list.
    - Deletion: Removing an existing element from the list.
    - Sorting: Arranging the elements in some order, ascending or descending
    - Merging: Combining two lists into a single one.

Linear Array

- A linear array is a list of finite no. n of homogeneous (same type) data elements. Such that:
  - The elements of the array are references respectively by an index set consisting of n consecutive numbers.
  - The elements are stored respectively in successive memory locations.
- The no. of elements of an array can be found by the following formula:

  Length=UB-LB+1

  where UB is Upper bound and LB is Lower bound index.
- Ex: If array Data has upper index 360 and lower index 100 then length=360-100+1=261

Representation of Linear Array in Memory

- Array elements are stored in sequential memory location. So it is not necessary to remember the location of every elements.

- Only the first element’s address is need to be memorized.

- The Successive elements address can be computed as follows:
  - LOC(LA[k])=Base(LA)+w(k-LB)

    where LOC(LA[k]) is the location of the element LA[k], Base(LA) is the address of the first element and w is the no. of words per memory cell.

Representation of Linear Array in Memory

1000	
1001	
1002	
1003	
1004	
.	
.	
.	

Computer Memory

1000	1	LA[1]
1001	1	
1002	1	
1003	1	
1004	2	LA[2]
1005	2	
1006	2	
1007	2	
1008	3	LA[3]
1009	3	
1010	3	
1011	3	

LA array with w=4

Traversing a Linear Array

- Traversing means accessing or processing each element of an array exactly once. This can be printing elements, summing the elements, finding sine value etc.

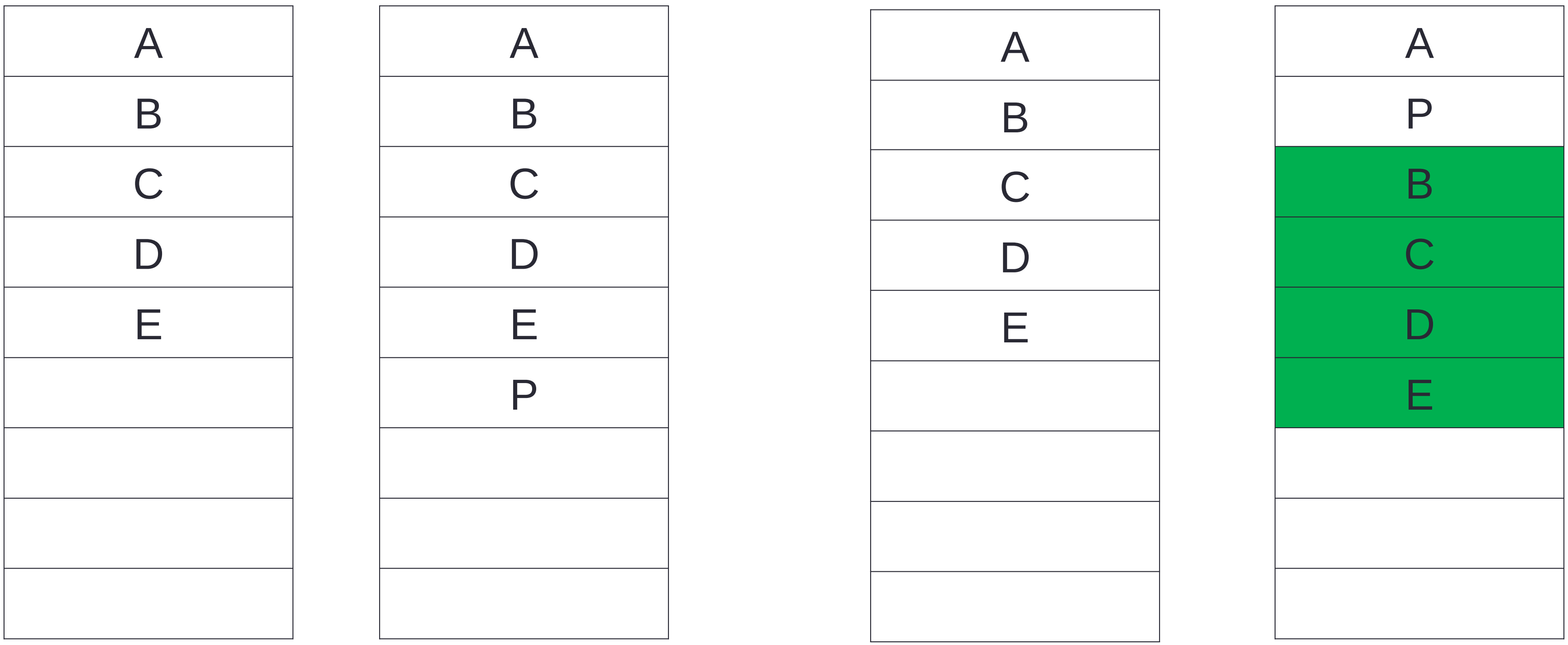
- The most common algorithm for Traversing an array LA with LB and UB is given below.

1. Set k:=LB
2. Repeat steps 3 and 4 while k<=UB
3. Apply Process to LA[k]
4. Set k:=k+1
5. Exit

Inserting an Element

- Inserting an element to an array is not easy all the time.
- If we want to add at the end, we have to make sure that there is available memory at the end of the array.
- If we want to add in the middle or other place than the end then we have to move the elements downwards to store the element.
- This is time consuming and so we move towards Linked list which give us an opportunity to insert elements any place without moving huge data.

Inserting an Element



Easy to add P after E

Difficult to add P after A

Inserting an Element

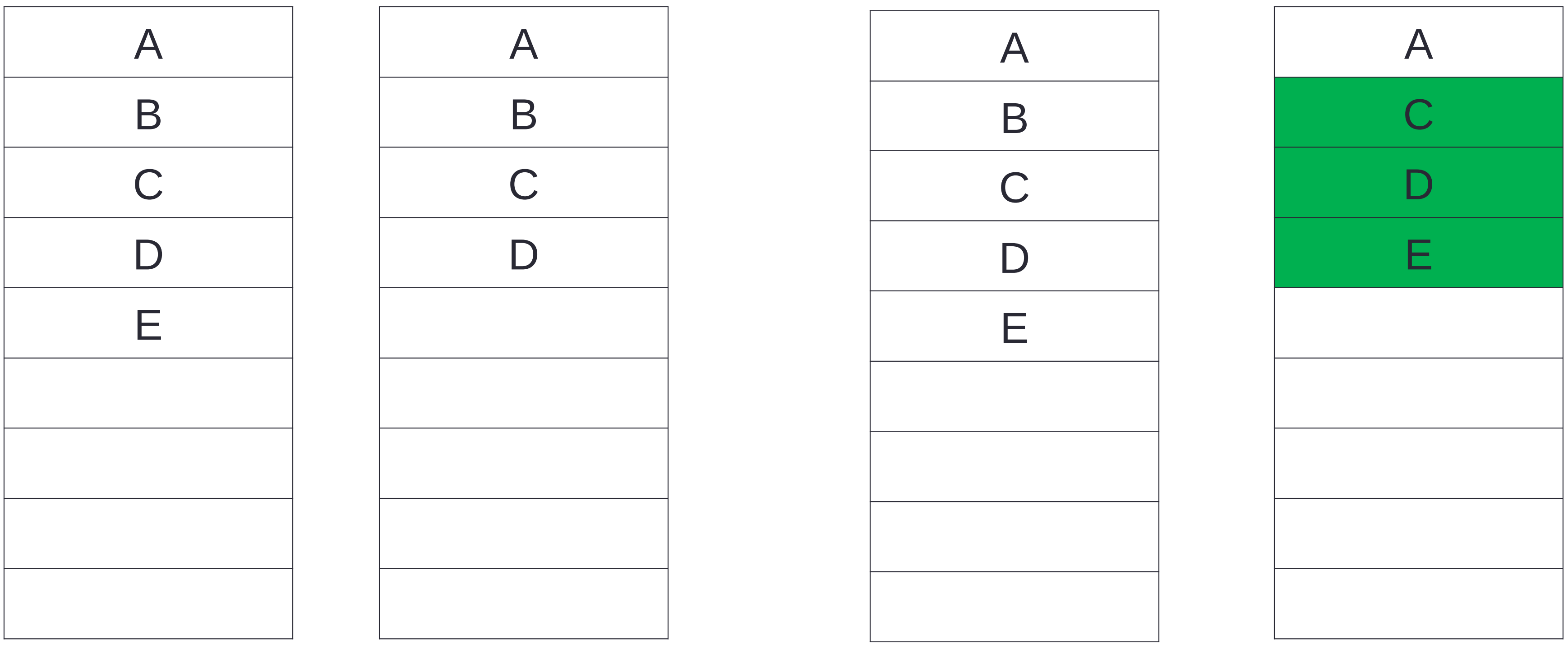
- This Algorithm add Item to kth position.
- INSERT(LA, N, K, Item)

1. Set j:=N
2. Repeat Steps 3 and 4 while j>=K
3. Set LA[j+1]:=LA[j]
4. Set j:=j-1
5. Set LA[k]=Item
6. Set N:=N+1
7. Exit

Deleting an Element

- Deleting an element is not also easy all the time.
- We can delete the last element without any effort.
- However, elements other than the last one incurs massive works.
- We have to move the elements upwards in order to fill the deleted element

Deleting an Element



Easy to Remove E

Difficult Remove B

Deleting an Element

This algorithm deletes the kth element and store it to Item.

DELETE(LA, N, K, Item)

1. Set Item:=LA[K]
2. Repeat for j:=K to N-1:

    Set LA[j]:=LA[j+1]
3. Set N:=N-1
4. Exit

Sorting

- Sorting refers to the process of rearranging elements to either increasing order or to decreasing order.
- There are a numbers of such sorting algorithms.
- Bubble sort is one of them.
- Others sorting algorithms are: Insertion sort, Selection sort, Merge sort, Radix sort etc.
- This algorithm finds the largest number from the array of n elements and place it to the end in the first pass.
- Then it continue this operation for numbers n-1, then for n-2 then for n-3 until for 1.
- In this way it is possible to get the n sorted data.

Bubble Sort

- Bubble(data, n)
- This algorithm sorts n numbers in ascending order.

1. Repeat steps 2 and 3 for k=1 to n-1
2. Set ptr:=1
3. Repeat while ptr<=n-k
   a. If data[ptr]>data[ptr+1] then
      Interchange data[ptr] and data[ptr+1]
   b. Set ptr:=ptr+1
4. Exit

Complexity of Bubble sort is n(n+1)/2

Bubble Sort (Example)

- Suppose we have five numbers 19, 13, 20, 8, 2. we can display the interchanges in the following way.
- Pass 1: 13, 19, 20, 8, 2

  13, 19, 20, 8, 2

  13, 19, 8, 20, 2

  13, 19, 8, 2, 20

- Pass 2: 13, 19, 8, 2, 20

  13, 8, 19, 2, 20

  13, 8, 2, 19, 20

- Pass 3: 8, 13, 2, 19, 20

  8, 2, 13, 19, 20

- Pass 4: 2, 8, 13, 19, 20

Searching

- Searching refers to finding the location of an item in a list.
- Search time depends on many factors.
  - The arrangement of the data (ascending or descending or unsorted).
  - The algorithm used to search.
  - The search criteria/ search item, etc.
- The most common Search algorithm is Linear Search.
- Other Search algorithms are: Binary Search, Binary Search Tree, etc.
- In Linear Search, data are searched from the beginning of the list until the desired data can be found or the list search ends.

Linear Search

- For a linear list of size n, the search time depends on whether the item is found at the beginning end or at ending end.
- For best case the time is 1, for worst case n. So the complexity is (n+1)/2

Linear(data, n, item, loc)

1. Set data[n+1]=item
2. Set loc:=1
3. Repeat while data[loc]<>item
4. Set loc:=loc+1
5. If loc==n+1 then set loc:=0
6. Exit

Binary Search

- Binary search can only be employed to a list of sorted data.
- It divides the total list into two parts and make a decision to which part the item may reside.
- Taking the desired part it then divide again and do the same thing.
- It perform the same operation until it finds the item or the search completes.
- Since it divides the list into two all the time the complexity is very low: $(\log_2 n)+1$

Binary Search

- Binary(data, ub, lb, item, loc)

1. Set beg:=lb, end:=ub and mid:=int((beg+end)/2)
2. Repeat steps 3 and 4 while beg<=end and data[mid]<>item
3. If item<data[mid], then
    a. set end:=mid-1
    b. else set beg:=mid+1
4. Set mid:=int((beg+end)/2)
5. If data[mid]=item then
    a. set loc:=mid
    b. Else loc:=null
6. exit

Binary Search Example

There are 13 data: 11, 22, 30, 33, 40, 44, 55, 60, 66, 77, 80, 88, 99. Initially beg:=1 end:=13 and mid:=7, say item=40 the steps for searching:

1. 11, 22, 30, 33, 40, 44, 55, 60, 66, 77, 80, 88, 99
2. Since 40<55 so (beg=1 end=6 mid=3)
3. 11, 22, 30, 33, 40, 44, 55, 60, 66, 77, 80, 88, 99
4. Since 40>=30 so (beg=4 end=6 mid=5)
5. 11, 22, 30, 33, 40, 44, 55, 60, 66, 77, 80, 88, 99
6. Since 40=40 (item=data[mid]), the search complete and the result location is 5 i.e. final mid value)

Multi Dimensional Array

- So far we talked about one dimensional array.
- Some times we need 2 or 3 dimension to represent data. For example if we want to deal with matrix we need 2D.
- 2D array: It is a collection of m.n elements, where each element is specified by a pair of integers (such as j, k) called the subscripts.
- The elements of a 2D array with m rows and n columns looks like as below.

A[1, 1] A[1, 2] ……A[1, n]
A[2, 1] A[2, 2] ……A[2, n]
……..   …….. ….. ……..
A[m, 1] A[m, 2] ……A[m, n]

Representation of 2D Arrays in Memory

- The elements of a 2D array is stored in memory in two way;
- row by row (first row then second row and so on) or
- Column by column (first column then second column and so on)

	1, 1	Row 1
	1, 2	
	2, 1	Row 2
	2, 2	
	3, 1	Row 3
	3, 2	
	4, 1	

	1, 1	Column 1
	2, 1	
	3, 1	
	4, 1	
	1, 2	Column 2
	2, 2	
	3, 2	

2D Arrays

- If the elements of an Array A with m rows and n columns are stored in row major order, the location of any elements A[i, j] can be found from the formula.
- loc(A[i, j])=Base(A)+w[n(i-1)+(j-1)]
- Similarly for column major order the location is
- loc(A[i, j])=Base(A)+w[m(j-1)+(i-1)]

- Example: Consider 25X4 matrix array score; base value is 200, w=4 what is the address of score[12, 3].
- For row major: 200+4[4(12-1)+(3-1)]=384
- For column major: 200+4[25(3-1)+(12-1)]=444

General Multi Dimensional Array

- An n dimensional array $m_1 x m_2 x \ldots\ldots. x m_n$ is a collection of $m_1 . m_2 \ldots\ldots. m_n$ data elements in which each element is specified by a list of n integers- such as k_1, k_2,….., k_n, called the subscript.
- As a 2D array we can also store elements as a row major order or column major order.
- For row major order the location can be found as:
- $Base(C)+w[(\ldots((E_1 L_2 + E_2)L_3+E_3)L_4+\ldots+E_{n-1})L_n + E_n)]$

- For column major order the location can be found as:
- $Base(C)+w[(((\ldots(E_n L_{n-1} + E_{n-1})L_{n-2})+\ldots+E_3)L_2+E_2)L_1+E_1)]$

General Multi Dimensional Array

- Where L_i is the no. of elements in the index set can be computed as L_i=UB-LB+1
- (For a given subscript K_i), the effective index E_i of L_i is the no. of indices preceding K_i in the index set and E_i can be computed as:
- E_i=K_i-lower bound.

- Example: Maze(2:8, -4:1, 6:10) is a 3D array with base=200, w=4, calculate Maze[5, -1, 8] address in a row major order and column major order.

General Multi Dimensional Array

Solution:

- L_1=8-2+1=7, L_2=1-(-4)+1=6, L_3=10-6+1=5,
- E_1=5-2=3, E_2=-1-(-4)=3, E_3=8-6=2, w=4, base=200.

- For row major order:
- Base + w[($E_1L_2+E_2)L_3+E_3$] = 200+4[(3.6+3)5+2]=628.

- For column major order:
- Base + w[($E_3L_2+E_2)L_1+E_1$] = 200+4[(2.6+3)7+3]=632.

Pointer and Pointer Array

- Pointer: A variable P is called a pointer if P points to an element in Data; where Data is an array.
- Pointer Array: An array PTR is called a pointer array if each element of PTR is a pointer.
- Let us consider the list below.

Group 1	Group 2	Group 3	Group 4
A	AA	AAA	AAAA
B	BB		BBBB
	CC		CCCC
	DD		
	EE		
	FF		
	GG		

Pointer and Pointer Array

- If we store the list, we can use a 2D array of size 4X7.
- Off Course it wastes 28-13=15 memory cell.
- The space can be properly utilized if a 1D array is employed and data are stored one group after another.
- Here the main problem is to access any specific group.
- This can be overcome if we store a sentinel (such as $$$) just after each group while storing data in the 1D array.
- With the sentinel we can find individual group; there off course still exist a problem; we have to traverse from the beginning.
- The best solution is to use a pointer array.

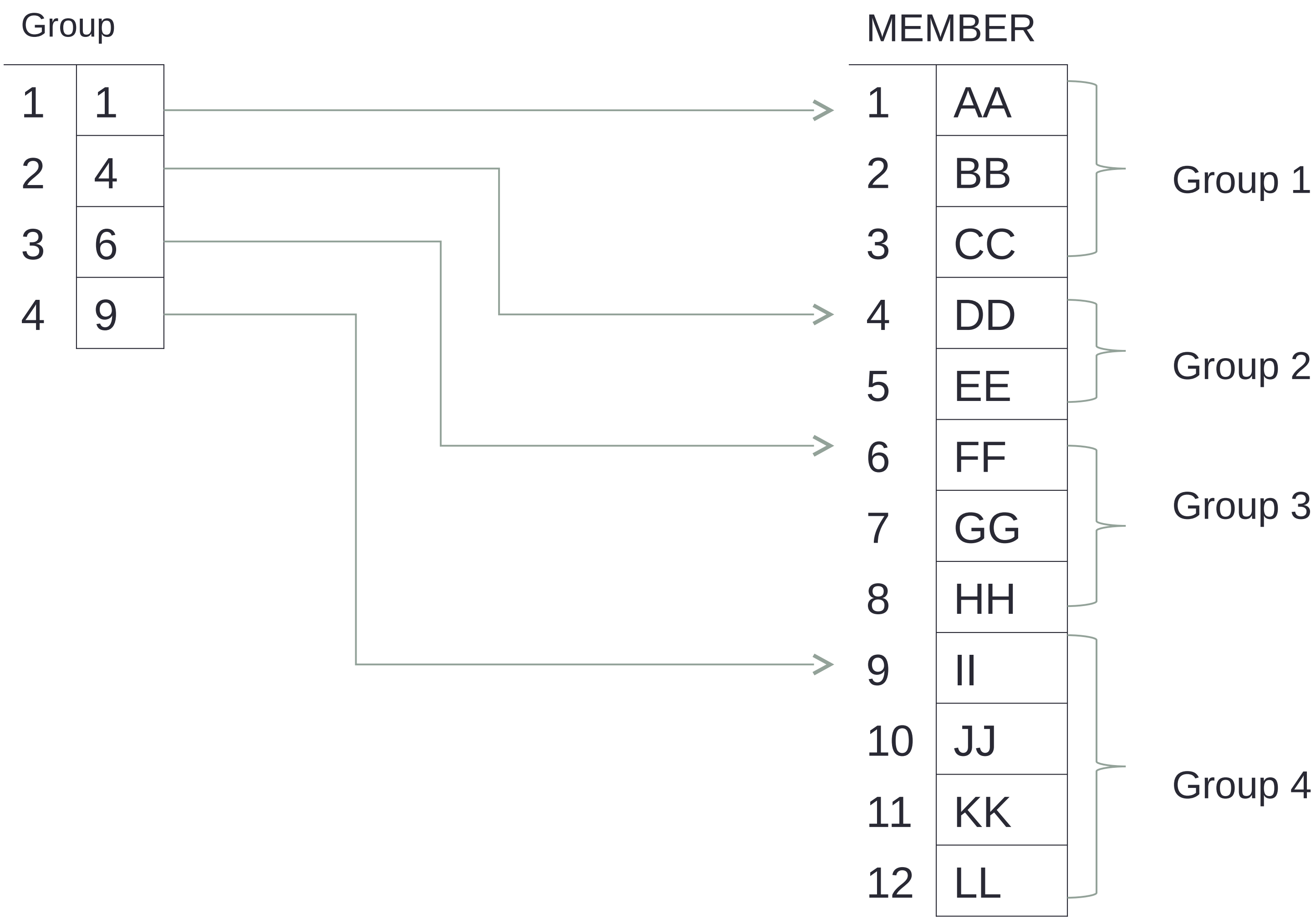
Pointer and Pointer Array

Pointer Array

- A pointer array is used to point each group of elements.
- The pointer array size depends on the no. of groups.
- Say Group is a pointer array and Member is a 1D array then Group[L] points to the first element of group L, Group[L+1] points to the first element of group L+1.
- Group[L] and Group[L+1]-1 contains respectively the first and last element of group L.
- Algorithm to display each elements of group L.

1. Set first:=Group[L] and last:=Group[L+1]-1
2. Repeat for k=first to last
3. Write Member[k]
4. Return

Pointer Array Example

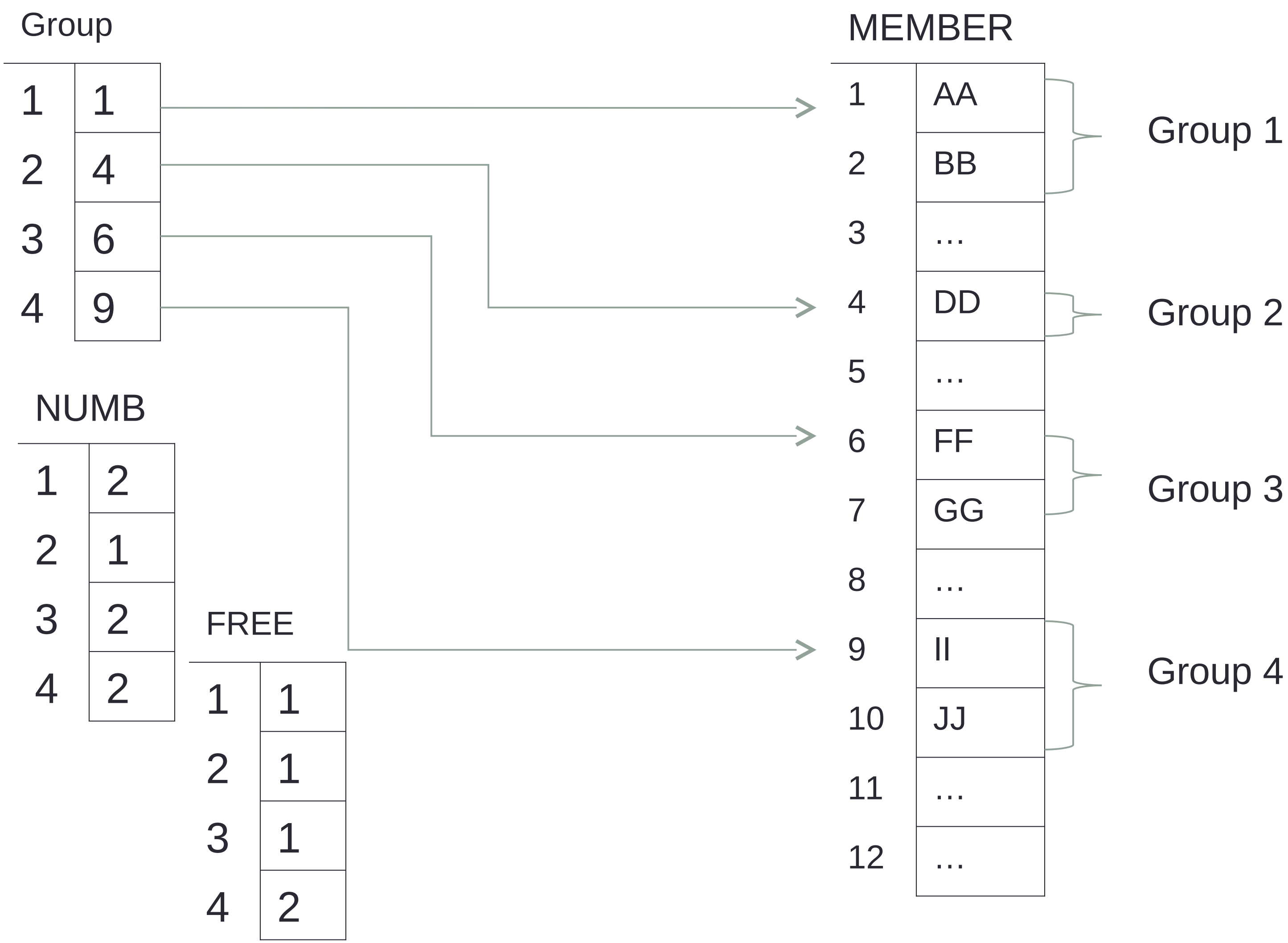


Pointer Array Other Version

- Actually in previous example of pointer array data need to be moved downward or upward if anyone wish to insert or delete any element respectively.
- A slightly different version however provide us some empty cells after each group which reduces the no. of data movement.
- In this method, an array NUMB is used which gives the no. of elements in each group.
- There may be another array FREE which gives the no. of free cells between two groups. Off course we can calculate the free space from the following formula.

FREE[k]=GROUP[k+1]-GROUP[k]-NUMB[k]

Another Pointer Array Example



Records

- A record is a collection of related data items each of which is called a field or attribute.
- Each data item itself may be a group item composed of sub items; those items which are indecomposable are called items or atoms or scalars.
- Although a record is a collection of related data items, it differ from a linear array in the following ways:

1. A record may be a collection of nonhomogeneous data (data items may have different data types).
2. The data items in a record are indexed by attribute names, so there may not be a natural ordering of its elements.

Sparse Matrices

- Matrices with a high proportion of zero entries are called Sparse Matrices.
- It is two types:
- (Lower) Triangular Matrix: All elements above the main diagonal are zero or, equivalently, nonzero entries can only occur on or bellow the main diagonal.
- Tridiagonal Matrix: Non zero entries can only occur on the diagonal or on elements immediately above or below the diagonal
- Since in case of Sparse matrix nonzero elements are high we can save memory space by discarding the zero elements in some way (discussed later)

Sparse Matrix Example

$$\begin{pmatrix} 4 & & & & \\ -2 & 3 & & & \\ 2 & 4 & -5 & & \\ 9 & 8 & -2 & -5 & \\ 2 & 4 & 5 & 8 & 9 \end{pmatrix}$$

Triangular Matrix

$$\begin{pmatrix} 4 & -3 & & & \\ -2 & 3 & 6 & & \\ & 4 & -5 & 7 & \\ & & -2 & -5 & -5 \\ & & & 8 & 9 \end{pmatrix}$$

Tridiagonal Matrix

Memory Save of a Sparse Matrix

- We can save almost half the memory requirement of a n square Sparse matrix A if we attempt to save only the nonzero elements as indicated by the figure.
- For this reason, we can use an one dimensional array B. That is, we let $B[1]=a_{1,1}$, $B[2]=a_{2,1}$, $B[3]=a_{2,2}$, $B[4]=a_{3,1}$ and so on.
- In this way B will contain $1+2+3+4+\ldots+n=(1/2)n(n+1)$ element rather than n^2.
- We need a formula that gives us the integer L in terms of j and k where $B[L]=a_{j,k}$.
- L is the no. of elements in the list up to and including $a_{j,k}$.

Relation between L and j,k

- There are 1+2+3+4+…+(j-1)=(1/2)j(j-1) elements in the rows above $a_{j,k}$, and there are k elements in row j up to and including $a_{j,k}$.
- Accordingly L=(1/2)j(j-1)+k yields the index that accesses the value $a_{j,k}$ from the linear array B.

$$\begin{pmatrix}
a_{11} \\
a_{21}\ a_{22} \\
a_{31}\ a_{32}\ a_{33} \\
a_{41}\ a_{42}\ a_{43}\ a_{44} \\
\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
a_{n1}\ \ a_{n2}\ \ a_{n3}\ \ a_{n4}\ \ a_{n5}\ \ldots\ldots\ a_{nn}
\end{pmatrix}$$