ICE-2231
(Data Structures and Algorithms)

Lecture on
Chapter-2: Arrays, Records, Pointers

By

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Data structures are classified as either *Linear* or *Nonlinear*.

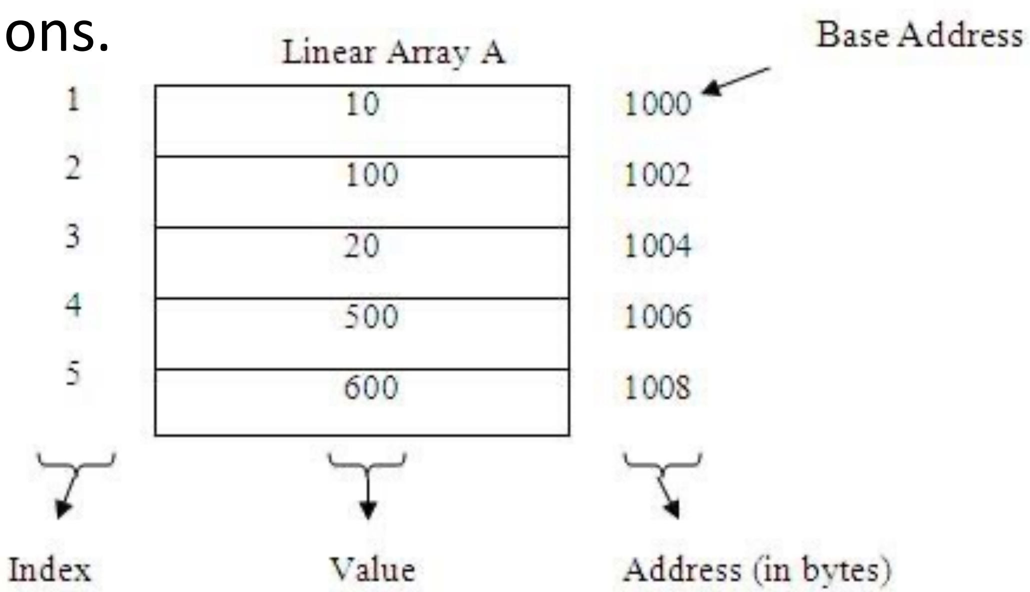
- A data structure is said to be *Linear* if its elements forms a sequence, or a linear list.
- There are **TWO** basic ways of representing such *linear structures* in memory.
  - One ways is to have the linear relationship between the elements represented by means of sequential memory locations. (For example, ARRAYS).
  - The other ways is to have the linear relationship between the elements represented by mean of pointers or links. (For example, Linked lists)

- *Nonlinear data structures (For example, tress and graphs) discussed later.*

Linear Arrays

A linear array is a list of finite number n of **HOMOGENEOUS** data elements (i.e., data elements of the same type) such that:

- The elements of the array are referenced respectively by an index set consisting of *n* consecutive numbers.
- The elements of the array are stored respectively in successive memory locations.



Linear Arrays

- The number *n* of elements is called **the length or size of the array**.
- In general, the length or the number of data elements of the array can be obtained from the index set by the formula.

$$\text{Length} = \text{UB} - \text{LB} + 1$$

where UB is the largest index, called the upper bound, and LB is the smallest index, called the lower bound of the array.

Note that, Length=UB when LB=1.

Linear Arrays: Example

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AMPLE 4.1

Let DATA be a 6-element linear array of integers such that

DATA[1] = 247 DATA[2] = 56 DATA[3] = 429 DATA[4] = 135 DATA[5] = 87 DATA[6] = 156

Sometimes we will denote such an array by simply writing

DATA: 247, 56, 429, 135, 87, 156

The array DATA is frequently pictured as in Fig. 4-1(*a*) or Fig. 4-1(*b*).

DATA

	DATA
1	247
2	56
3	429
4	135
5	87
6	156

(*a*)

DATA

247	56	429	135	87	156
1	2	3	4	5	6

(*b*)

Fig. 4-1

Linear Arrays: Indexing Example

- An automobile company uses an array AUTO to record the number of automobiles sold each year from 1930 through 1984.

- Rather than beginning the index set with 1, it is more useful to begin the index set with 1930 so that

  AUTO[K]=Number of automobiles sold in the year K,

  Then, LB=1930 and UB=1984 of AUTO

  Length=UB-LB+1
  =1984-1930+1=55

- On implementation, each programming language has its own rules for declaring arrays. Each such declaration must give, implicitly , THREE items of information,
  - The **NAME** of the array,
  - The **DATA TYPES** of the array
  - The **INDEX SET** of the array

Representation of LA in Memory

- ✓ Let LA be a linear array in the memory of the computer.

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

- ✓ The elements of LA are stored in successive memory cells.
- ✓ Accordingly, the computer does not need to 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)*-called the base address of LA

Representation of LA in Memory

- ✓ Using the base address of LA, the computer calculates the address of any element of LA by the following formula:

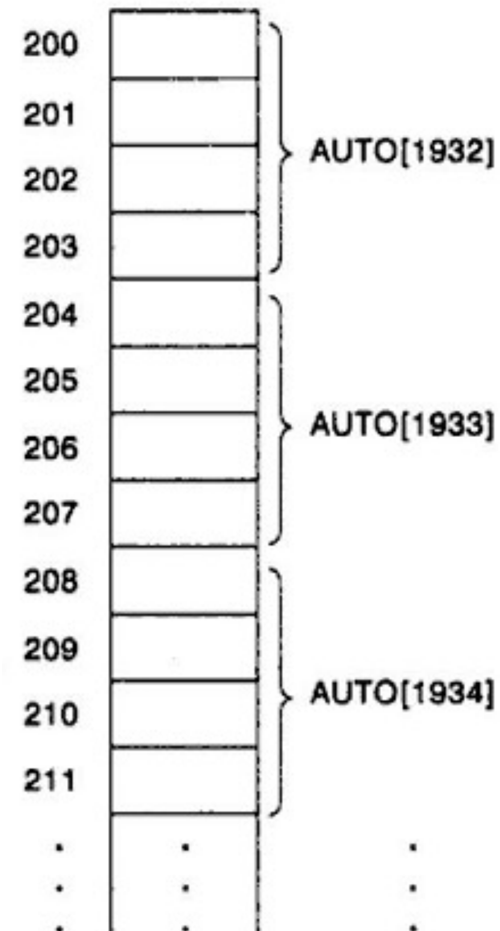
$$LOC(LA[K])=\mathit{Base}(LA)+w(K\text{-lower bound})$$

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

- ✓ The time to calculate LOC (LA[K]) is essentially the same for any value of K.
- ✓ Given any subscript K, one can locate and access the content of LA[K] without scanning any other element of LA.

Example: Representation of LA in Memory

- Consider the array AUTO which records the number of automobiles sold each year from 1932 through 1984.
- Suppose AUTO appears in memory as pictured below



- Here, Base (AUTO)=200, and
- w=4 words per memory cell for AUTO.

LOC (AUTO[1932])= 200

LOC (AUTO[1933])= 204

LOC (AUTO[1934])= 208

- Address of the array element for the year K=1965 can be obtained:

LOC(AUTO[1965])=**Base(AUTO)+w(1965-lower bound)**

= 200+4(1965-1932)=332

LOC(LA[K])=*Base*(LA)+w(K-lower bound)

Can Linear Arrays be indexed?

- A collection A of data elements is said to be indexed if any element of A, which we shall call A_k , can be located and processed in the time that is independent of K.
- This is very important property of linear arrays

Traversing Linear Arrays A: Algorithm

A is a linear array with LB and UB

Step 1. [Initialize counter] Set K:=LB

Step 2. Repeat Step 3 and 4 while K<=UB [Repeat while loop]

Step 3. [Visit element] Apply PROCESS to A[K].

Step 4. [Increase counter] Set K:=K+1.

[End of Step 2 loop.]

Step 5. Exit.

Step 1. Repeat for K=LB to UB [Repeat for loop]

[Visit element] Apply PROCESS to A[K].

[End of Step 2 loop.]

Step 2. Exit.

Traversing Linear Arrays: Example

Consider the array AUTO in Example 4.1(*b*), which records the number of automobiles sold each year from 1932 through 1984. Each of the following modules, which carry out the given operation, involves traversing AUTO.

(*a*) Find the number NUM of years during which more than 300 automobiles were sold.

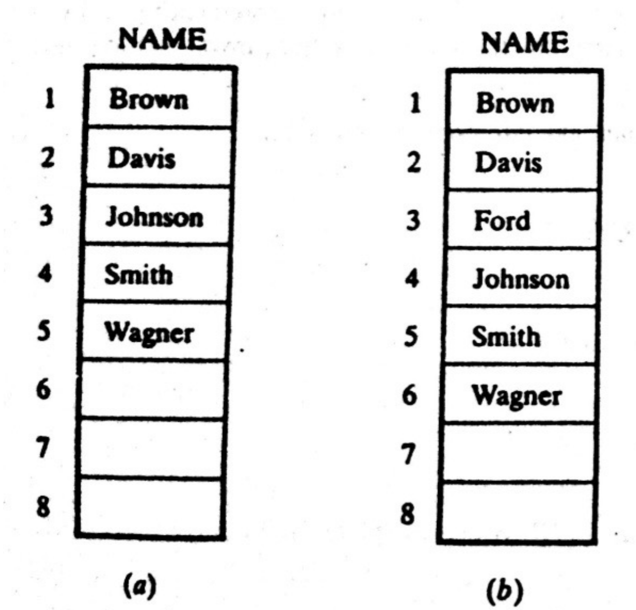
1. [Initialization step.] Set NUM := 0.
2. Repeat for K = 1932 to 1984:
   If AUTO[K] > 300, then: Set NUM := NUM + 1.
   [End of loop.]
3. Return.

(*b*) Print each year and the number of automobiles sold in that year.

1. Repeat for K = 1932 to 1984:
   Write: K, AUTO[K].
   [End of loop.]
2. Return.

Inserting elements in a Linear Arrays:

- ✓ Let A be a collection of data elements in the computer memory.
- ✓ Inserting refer to the operation of **ADDING** another element to the collection.
- ✓ Inserting an element at the "end" of the linear array can be **EASILY** done provided the memory space allocating for the array is large enough to accommodate the additional element.
- ✓ Inserting an element in the middle of the array is **RELATIVELY COMPLICATED TASK.**
- ✓ On an average, half of the elements must be moved downward to new locations to accommodate the elements and keep the order of the other elements.



Inserting elements in a LA: Algorithm

INSERT(LA, N, K, ITEM) [**inserts an element ITEM into Kth 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.

- The elements are moved in reverse order . First LA[N], then LA[N-1],……and last LA[K]; otherwise data might be erased.

Instant Test-1:

Consider the linear arrays:

XXX (10 : 55),

YYY (-10 : 15), and

ZZZ (25)

a) Find the number of element in each array.

We know Length=UB-LB+1

Accordingly, Length (XXX) = 55 - 10 + 1= 46

Length (YYY) = 15-(-10)+1 = 26

Length (ZZZ) = 25-1+1= 25

Instant Test-2:

Consider the linear arrays:

XXX (10 : 65),

YYY (-10 : 15), and

ZZZ (25)

b) Suppose Base (XXX) = 300 and w= 4 words per memory cell for XXX.

- **Find the address of XXX [15]**

  XXX [35]

  XXX [75]

We know the formula: LOC (XXX[k])= Base (XXX)+w (k-LB)

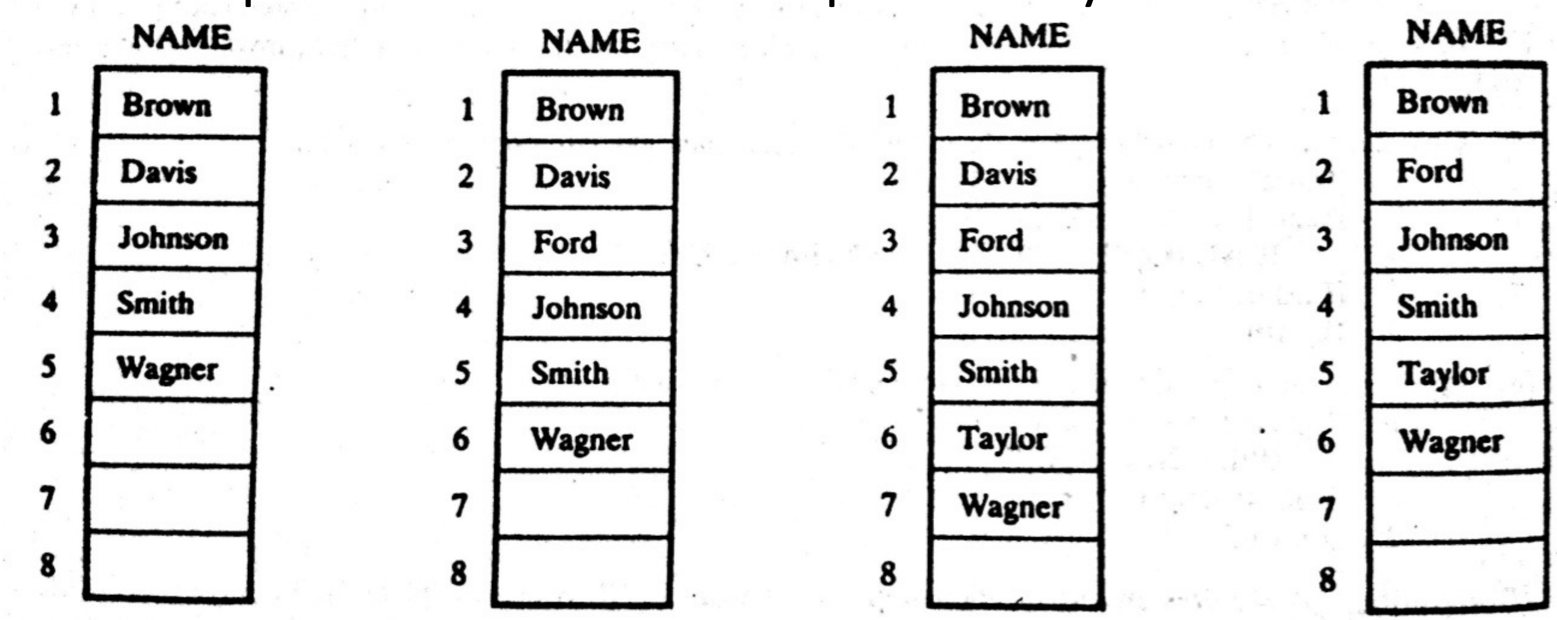
Hence, LOC (XXX[15])= 300 + 4 (15-10) = 320

LOC (XXX [35])= 300 + 4 (35-10)= 400

XXX [75] is not an element of XXX, since 75 exceeds UB=65

Deleting elements from a Linear Arrays:

- ✓ Deleting refers to the operation of removing one of the elements from A.
- ✓ Deleting an element at the “end” of the linear array present no difficulties (**EASILY).**
- ✓ But deleting an element somewhere in the middle of the array would require that each of the subsequent element be moved one location upward in order to fill-up the array.



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

Deleting elements from a LA: Algorithm

DELETE(LA, N, K, ITEM)

(This algorithm deletes the Kth element from LA)

1. Set ITEM:=LA[K]
2. Repeat for J=K to N-1:

   [Move J+1th element upward.] Set LA[J]:=LA[J+1]

   [End of Step 2 loop.]

3. [Reset the number N of element in LA] Set N:=N-1.
4. Exit.

Sorting

Let A be a 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 $A[a] < A[2] < A[3] < \ldots\ldots < A[N]$

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

Sorting: BUBBLE SORT

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 66 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 57 to yield:

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

At the end of the first pass, the largest number ,85 has moved to the last position.

Rest of the number are not sorted.

Sorting: BUBBLE SORT

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 positi

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 involve an interchange.

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

...after the seventh pass. (Observe that in this example, the list was act

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

Bubble Sort: Algorithm

BUBBLE (DATA, N)

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

Step 1. Repeat Steps 2 and 3 for K=1 to N-1.

Step 2. Set PTR:=1 [Initialize pass pointer PTR]

Step 3. Repeat while PTR<=N-K [Execute pass.]

(a) If DATA[PTR] > DATA[PTR+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.]

Step 4. Exit.

Complexity of BUBBLE SORT

- Traditionally, the time for this sorting algorithm is measured in terms of the number of comparisons.
- The number f(n) of comparisons in the bubble sort is easily computed.
- Specifically, there are n-1 comparisons during the first pass, which placed the largest element to the last position; there are n-2 comparisons in the second step, which placed the second largest element in the next-to-the last position, and so on. Thus.

$$F(n)=(n-1)+(n-2)+\dots+2+1$$
$$=n(n-1)/2=n^2/2+O(n)$$
$$=O(n^2)$$

Searching

- ✓ Searching refers to the operation of finding the location LOC of ITEM in Data, or printing some message that ITEM does not appear there.
- ✓ The search is said to be *successful* if ITEM does appear in Data and *unsuccessful* otherwise.
- ✓ There are many different searching algorithms. The algorithm that one chooses generally depends on the way the information is DATA is organized.
- ✓ A simple searching algorithm: Linear Search Algorithm
- ✓ The well known algorithm: Binary search Algorithm

Linear Search Algorithm

- ✓ Suppose DATA is a linear array with n elements. Given no other information about DATA.
- ✓ Simple way to search for a given ITEM in DATA is to compare ITEM with each element of DATA one by one.
- ✓ Suppose we want to know whether Jhon appears in the array or not.
- ✓ Again, Suppose, we want to know whether Moon appears in the array or not.

Adams
Charlie
Rasha
Moon
Rock
Smith

Adams
Charlie
Rasha
Moon
Rock
Smith
Jhon

Adams
Charlie
Rasha
Moon
Rock
Smith
Moon

Linear Search Algorithm: Example

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	0	1	2	3	4	5	6	7
list	65	20	10	55	32	12	50	99

search element **12**

Step 1:

search element (12) is compared with first element (65)

	0	1	2	3	4	5	6	7
list	65	20	10	55	32	12	50	99
	12							

Both are not matching. So move to next element

Step 2:

search element (12) is compared with next element (20)

	0	1	2	3	4	5	6	7
list	65	20	10	55	32	12	50	99
		12						

Both are not matching. So move to next element

Step 3:

search element (12) is compared with next element (10)

	0	1	2	3	4	5	6	7
list	65	20	10	55	32	12	50	99
			12					

Both are not matching. So move to next element

Step 4:

search element (12) is compared with next element (55)

	0	1	2	3	4	5	6	7
list	65	20	10	55	32	12	50	99
				12				

Both are not matching. So move to next element

Step 5:

search element (12) is compared with next element (32)

	0	1	2	3	4	5	6	7
list	65	20	10	55	32	12	50	99
					12			

Both are not matching. So move to next element

Step 6:

search element (12) is compared with next element (12)

	0	1	2	3	4	5	6	7
list	65	20	10	55	32	12	50	99
						12		

Both are matching. So we stop comparing and display element found at index 5.

Searching: Linear Search Algorithm

LINEAR (DATA, N, ITEM, LOC)

Step 1. [Insert ITEM at the end of DATA] Set DATA[N+1]:=ITEM

Step 2. [Initialize counter] Set LOC:=1.

Step 3. [Search for ITEM.]

Repeat while Data [LOC]$\neq ITEM$:

Set LOC:=LOC+1.

[End of loop.]

Step 4. [Successful?] IF LOC=N+1, then: Set LOC:=0;

Step 5. Exit.

Linear Search Algorithm: Complexity

- ✓ The complexity of this algorithm is measured by the number f(n) of comparison required to find ITEM where DATA contains n elements.
- ✓ Two important cases to consider are:
  - ✓ **The average case**, and
  - ✓ **The worst case**

The running time of the average case uses the probabilistic notation of expectation.

- ✓ Suppose, p_k is the probability that ITEM appears in DATA[K], and
- ✓ suppose, q is the probability that ITEM does not appear in DATA.
- ✓ Since, the algorithm uses k comparisons when ITEM appears in DATA [K], the average number of comparisons is given by

$$f(n) = 1.p_1 + 2.p_2 + \ldots\ldots.n.p_n + (n+1)q$$

- ✓ In particular, q is very small, and ITEM appears with equl probability in each element of DATA. Then $q \approx 0$ and each $p_i = 1/n$.
- ✓ Accordingly $f(n) = 1.\frac{1}{n} + 2.\frac{1}{n} + 3.\frac{1}{n} + \ldots\ldots n.\frac{1}{n} + (n+1).0$
- ✓ $= (1+2+\ldots+n).\frac{1}{n} = \frac{n(n+1)}{2}.\frac{1}{n} = \frac{n+1}{2}$

Linear Search Algorithm: Complexity

The worst case occurs when one must search through the entire array DATA, when ITEM does not appear in DATA.

Algorithm Requires f(n)= *n+1* comparison.

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

Binary Search:

Suppose DATA is an array which is sorted in ***INCREASING ORDER***, or equivalently, alphabetically.

Then, *Binary Search algorithm* is an extremely efficient searching algorithm to find the location LOC of a given ITEM of information in DATA.

Binary search algorithm applied to array DATA works as follows:

DATA[BEG], DATA[BEG+1], DATA[BEG+2],........, DATA[END]

This algorithm compares ITEM with the middle element DATA [MID] of the segment, where MID is obtained by

MID=INT((BEG+END)/2)

- ✓ If DATA[MID]=ITEM, then the search is **SUCCESSFUL**.

  We set LOC:=MID

  ....Otherwise a new segment of DATA is obtained.

Binary Search:

(a) If ITEM < DATA[MID], then ITEM can appear only in the left half of the segment:

DATA[BEG], DATA[BEG+1], ...DATA[MID-1]

So, we resent END:=MID-1 and begin searching again.

(b) If ITEM> DATA[MID], then ITEM appear only in the right half of the segment:

DATA[MID+1], DATA[MID+2],..........DATA[END]

So, we reset BEG:=MID+1 and begin searching.

- ✓ Initially, we begin with entire array DATA, i.e. We begin wit BEG=1 and END=n, or more generally, with BEG=LB and END=UB.

- ✓ If ITEM is not in DATA, then eventually we obtain

END< BEG

Which means the search is **Unsuccessful**

So, SET LOC:=NULL (OUT side of DATA indices)

Binary Search: : Example

Searching the array below for the value **42**:

											10					
	-4	2	7	10	15	20	22	25	30	36	42	50	56	68	85	92	103

min

mid

max

Binary Search: Algorithm

BINARY (DATA, LB, UB, ITEM, LOC)

(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<=END and DATA[MID] ≠ 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

Binary Search: Limitations

Your Task

Linear Arrays/ One Dimensional Array

- In general, the length or the number of data elements of the array can be obtained from the index set by the formula.

$$\text{Length} = \text{UB} - \text{LB} + 1$$

where UB is the largest index, called the upper bound, and LB is the smallest index, called the lower bound of the array.

✓ Using the base address of a array LA, the computer calculates the address of any element of LA by the following formula:

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

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

Two Dimensional Array

- A two dimensional $m \times n$ array A is a collection of $m.n$ data elements such that each element is specified by a pair of integer, called subscripts(J,K), with the property that…

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

- A two dimensional arrays are called **metrices** in mathematics and **tables** in business application; hence two-dimensional arrays are sometimes called *matrix arrays*.

Two Dimensional Array: Representation in Memory

Let A be a two-dimensional array $m \times n$ array.

Although A is pictured as a rectangular array of elements with *m* rows and *n* columns,

Student	Test 1	Test 2	Test 3	Test 4
1	84	73	88	81
2	95	100	88	96
3	72	66	77	72
⋮	⋮	⋮	⋮	⋮
25	78	82	70	85

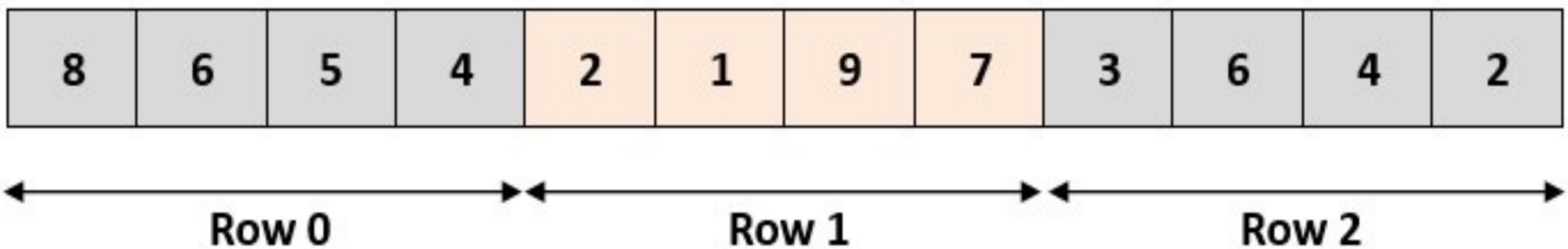
The array will be represented by a block of *m.n* sequential memory location.

Two Dimensional Array: Representation in Memory

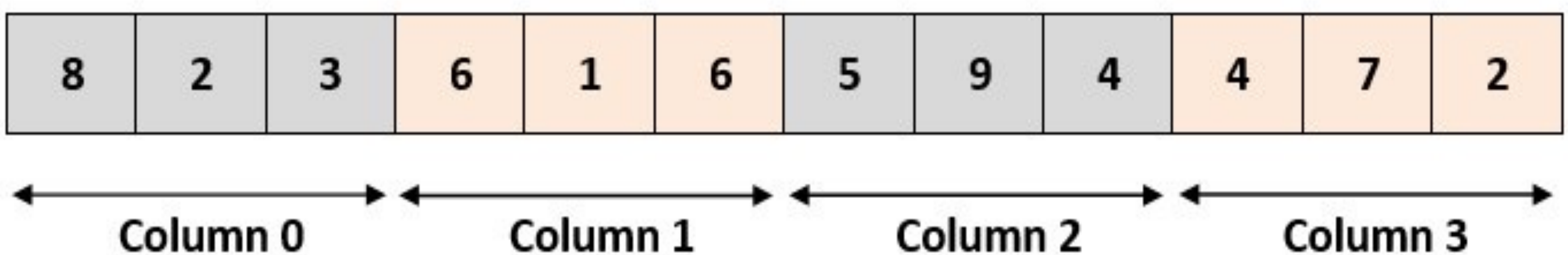
The programming language will store the array A either

- Column by Column – called *Column Major Order (CMO)*
- Row by Row-called Row Major Order(RMO)

Row-Major (Row Wise Arrangement)



Column-Major (Column Wise Arrangement)



Two Dimensional Array: Accessing Element

For one-dimensional array, the computer uses the formula

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

to find the address of LA[K] in time independent of K, where w is the number of words per memory cell for the array LA and 1 is the lower bound of the index set of LA.

A similar situation also holds for any two-dimensional $m \times n$ array A. Computer keep track of *Base*(A)-the address of the first element A[1,1] of A and compute the address LOC(A[J,K]) of A[J,K] using the formula:

- for CMO, LOC(A[J,K])=*Base*(A)+w[M(K-1)+(J-1)]
- For RMO, LOC(A[J,K])=*Base*(A)+w[N(J-1)+(K-1)]

Tech Yourself: Example 4.12,

Two Dimensional Array: Problem

- Given: 3×4 Integer matrix with base address 1000.
- Find out the location of A[3][2].

Using Row major Formula

- The Location of element A[i, j] can be obtained by evaluating expression:
  LOC (A [i, j]) = Base_Address + W [M (i) + (j)]
  Here,
  Base_Address is the address of first element in the array.
  W is the word size. It means number of bytes occupied by each element.
  N is number of rows in array.
  M is number of columns in array.

Two Dimensional Array: Problem

- Given: 3×4 Integer matrix with base address 1000.
- Find out the location of A[3][2].

Using Row major Formula

LOC (A [i, j]) = Base_Address + W [M (i) + (j)]

- Base (A) : 1000
- w : 2 (because an integer takes 2 bytes in memory)
- N : 4
- J : 3
- K : 2
- Now put these values in the given formula as below:
- LOC (A [3, 2]) = 1000 + 2 [4 (3-1) + (2-1)]
- = 1000 + 2 [4 (2) + 1]
- = 1000 + 2 [8 + 1]
- = 1000 + 2 [9]
- = 1000 + 18
- = 1018

Two Dimensional Array: Problem

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- Given: 3×4 Integer matrix with base address 1000.
- Find out the location of A[3][2].

Using Column major Formula

- LOC (A [J, K]) = Base (A) + w [M (K-1) + (J-1)]
- Here
- LOC (A [J, K]) : is the location of the element in the Jth row and Kth column.
- Base (A) : is the base address of the array A.
- w : is the number of bytes required to store single element of the array A.
- M : is the total number of rows in the array.
- J : is the row number of the element.
- K : is the column number of the element.

Two Dimensional Array: Problem

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- Given: 3×4 Integer matrix with base address 1000.
- Find out the location of A[3][2].

Using Column major Formula

- Base (A) : 1000
- w : 2 (because an integer takes 2 bytes in memory)
- N : 4
- J : 3
- K : 2

- LOC (A [3, 2]) = 1000 + 2 [3 (2-1) + (3-1)]
- = 1000 + 2 [3 (1) + 2]
- = 1000 + 2 [3 + 2]
- = 1000 + 2 [5]
- = 1000 + 10
- = 1010

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

Two Dimensional Array: Instant Test

1. A matrix B[10][20] is stored in the memory with each element requiring 2 bytes of storage. If the base address at B[2][1] is 2140, find the address of B[5][4]
   i. when the matrix is stored in Column Major Wise.
   ii. when the matrix is stored in Row Major Wise.

i. LOC(B[J,K]) =Base (B)+w[M(K-1)+(J-1)]

$$\begin{aligned} LOC(B[5,4]) &= 2140 + 2[10(4-1) + (5-2)] \\ &= 2140 + 2[10 \times 3 + 3] \\ &= 2140 + 2[30 + 3] \\ &= 2140 + 2[33] \\ &= 2140 + 66 \\ &= 2206 \end{aligned}$$

ii. LOC(B[J,K])=Base (B)+w[M(J-1)+(K-1)]

= ?

Pointers

Let DATA be any array. A variable **P** is called a *pointer* if **P** "points" to an element in DATA, i.e., if **P** contains the address of an element in DATA.

Pointer Arrays

An array **PTR** is called a *pointer array* if each element of **PTR** is a pointer

Pointer and Pointer array are used to facilitate the processing the information in DATA

Group 1	Group 2	Group 3	Group 4
Evans	Conrad	Davis	Baker
Harris	Felt	Segal	Cooper
Lewis	Glass		Ford
Shaw	Hill		Gray
	King		Jones
	Penn		Reed
	Silver		
	Troy		
	Wagner		

How the membership list can be stored in memory keeping track of the different groups?

Possible Solutions to keep in memory

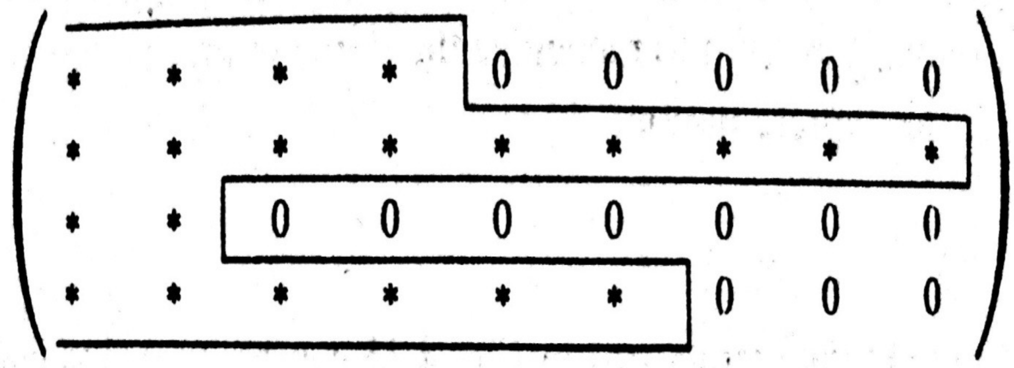
- Possible solutions: using
  - ➢ 2D $4 \times n$ array where each row contain a group, or
  - ➢ 2D $n \times 4$ array where each column contains a group.
- These structure allows us to access each individual group, much space will be wasted when the groups vary greatly in size.

Group 1	Group 2	Group 3	Group 4
Evans	Conrad	Davis	Baker
Harris	Felt	Segal	Cooper
Lewis	Glass		Ford
Shaw	Hill		Gray
	King		Jones
	Penn		Reed
	Silver		
	Troy		
	Wagner		

- Here the data will require at least a 36-element 4 x 9 or 9 x 4 arrays to store the 21 names, which is almost twice the space that is necessary.

Representation of 4 x 9 array

Group 1	Group 2	Group 3	Group 4
Evans	Conrad	Davis	Baker
Harris	Felt	Segal	Cooper
Lewis	Glass		Ford
Shaw	Hill		Gray
	King		Jones
	Penn		Reed
	Silver		
	Troy		
	Wagner		



Jagged array

- **Arrays whose rows –or column- begin with different numbers of data elements and each with unused storage locations are said to be *jagged*.**

Possible Solutions to keep in memory

One group after another

	MEMBER	
1	Evans	Group-1
2	Harris	
3	Lewis	
4	Shaw	
5	Conrad	Group-2
.		
.		
13	Wagner	
14	Davis	Group -3
15	Segal	
16	Baker	Group-4
.		
.		
20	Jones	
21	Reed	

- ✓ Space-Efficient
- ✓ Entire list can be easily processed
- ✓ One can easily print all the names on the list.

- ✓ There is no way to access any particular group.
- ✓ There is no way to find and print only the names in the third group.

Possible Solutions to keep in memory

	MEMBER	
1	Evans	Group-1
2	Harris	
3	Lewis	
4	Shaw	
5	$$$	
6	Conrad	Group-2
.		
.		
14	Wagner	
15	$$$	
16	Davis	Group-3
17	Segal	
18	$$$	
19	Baker	Group-4
.		
.		
20	Jones	
21	Reed	
25	$$$	

- **Uses only a few extra memory cells- one for each group.**
- **Any one now find those names in he third group by locating those names which appear after the second sentinel**

- **The list still must be traversed from the beginning in order to recognize the third group.**
- **The different groups are not indexed with this representation.**

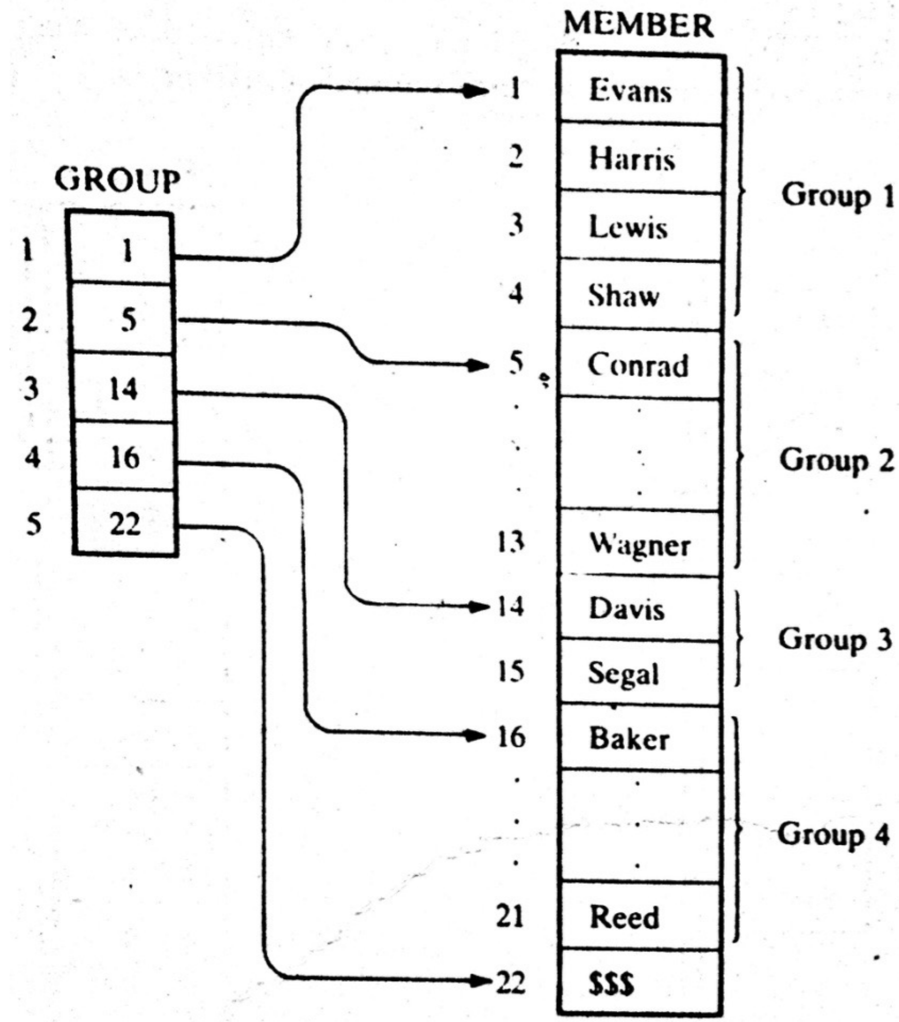
POINTER ARRAYS

ICE 2261

Pointer arrays is introduced in the last two space-efficient data structure.

The pointer array contains the locations of the…..

- ✓ Different groups, or
- ✓ First element in the different groups.
- ✓ GROUP[L] and GROUP[L+1]-1 contain respectively, the first and last element in group L.



- Suppose L=3
- 1st Element of grp 3?
- GROUP[L]=GROUP[3]

= 14

= Davis

- Last Element of grp 3?

Pls Try

POINTER ARRAYS: Example

Last element of grp 3

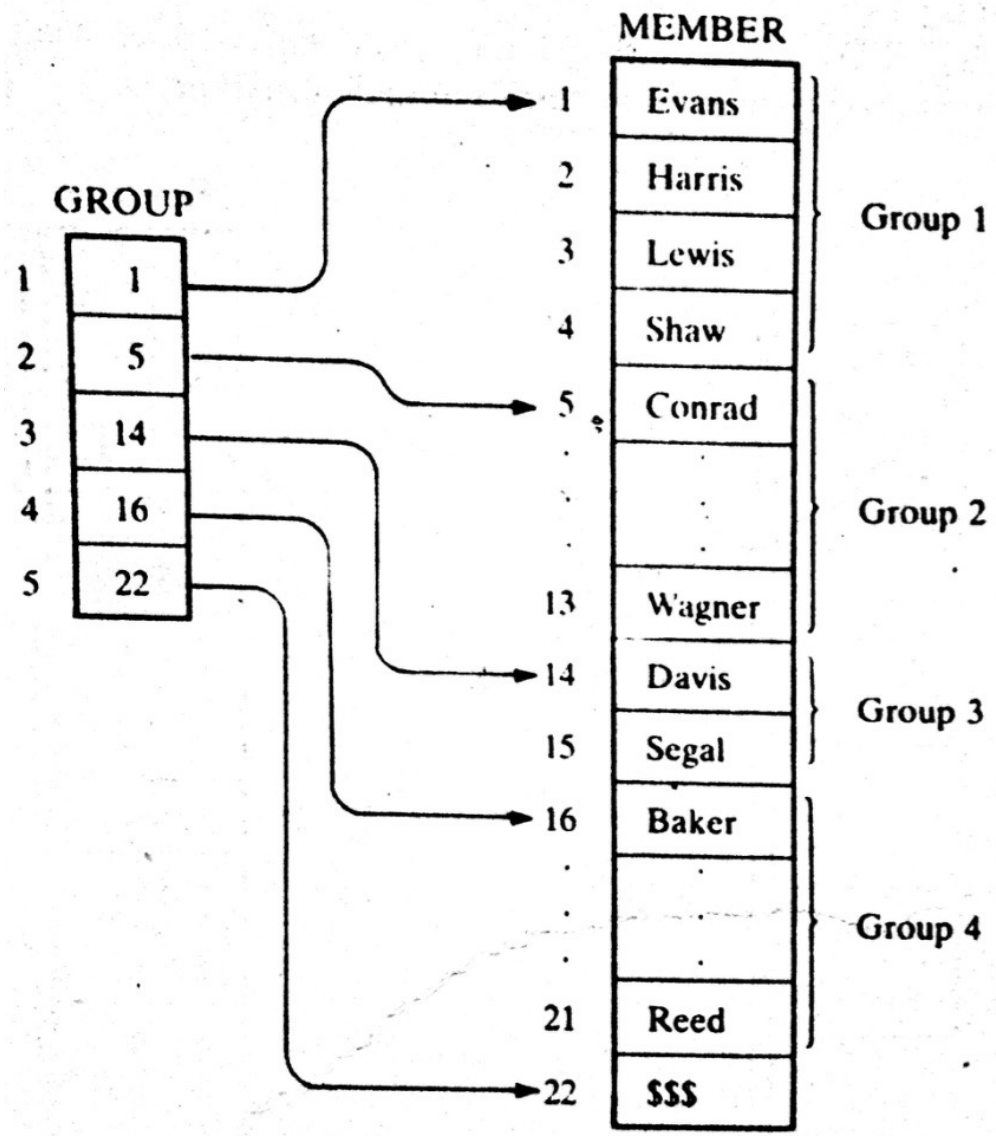
GROUP[L+1]-1

=GROUP[3+1]-1

=16-1

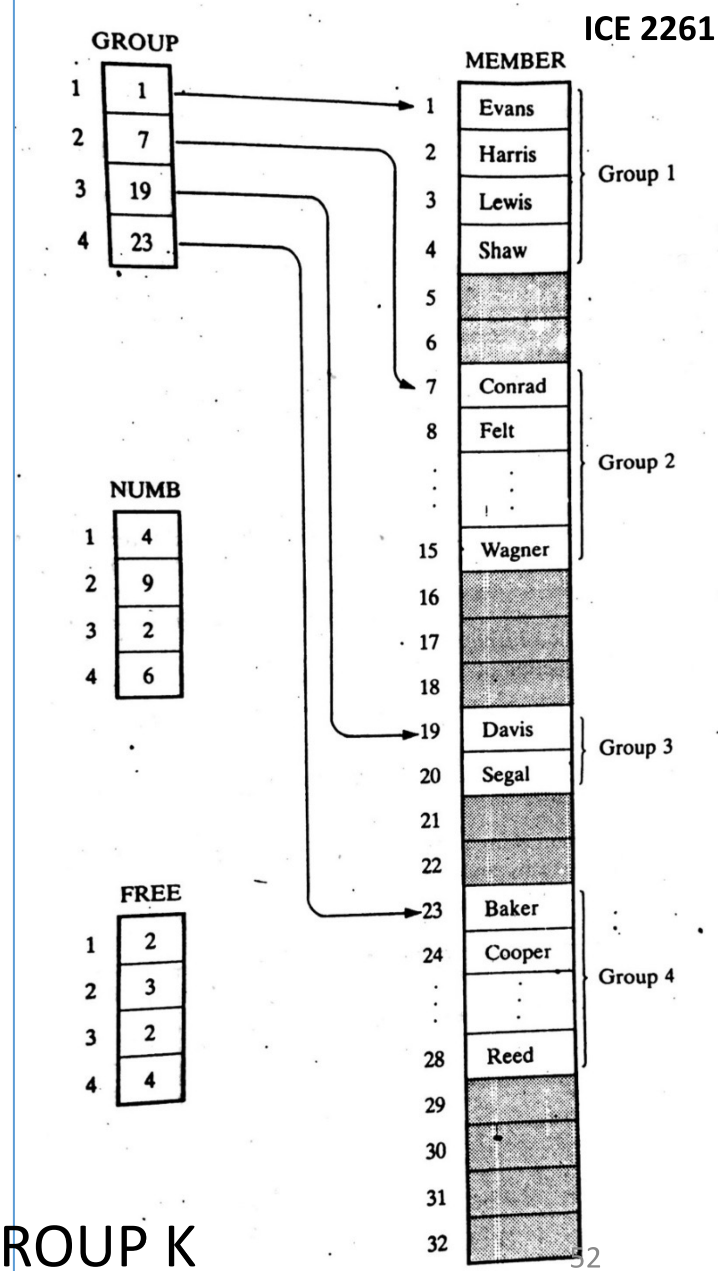
=15

= Segel



POINTER ARRAYS: Extended

- Here unused memory cells are indicated by the shading.
- Observe that now there are some empty cells between the groups.
- Accordingly, a new element may be inserted in a new group without necessarily moving the elements in any other group.
- Using the data structure, one requires an array NUMB which gives the number of elements in each group.
- Observe that GROUP[K+1]-GROUP[K] is the total number of space available for group K. Hence



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

Gives the number of empty cells following GROUP K

POINTER ARRAYS: Extended, Example

ICE 2261

Suppose, we want to print only the number of FREE cells of GROUP 2. Then

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

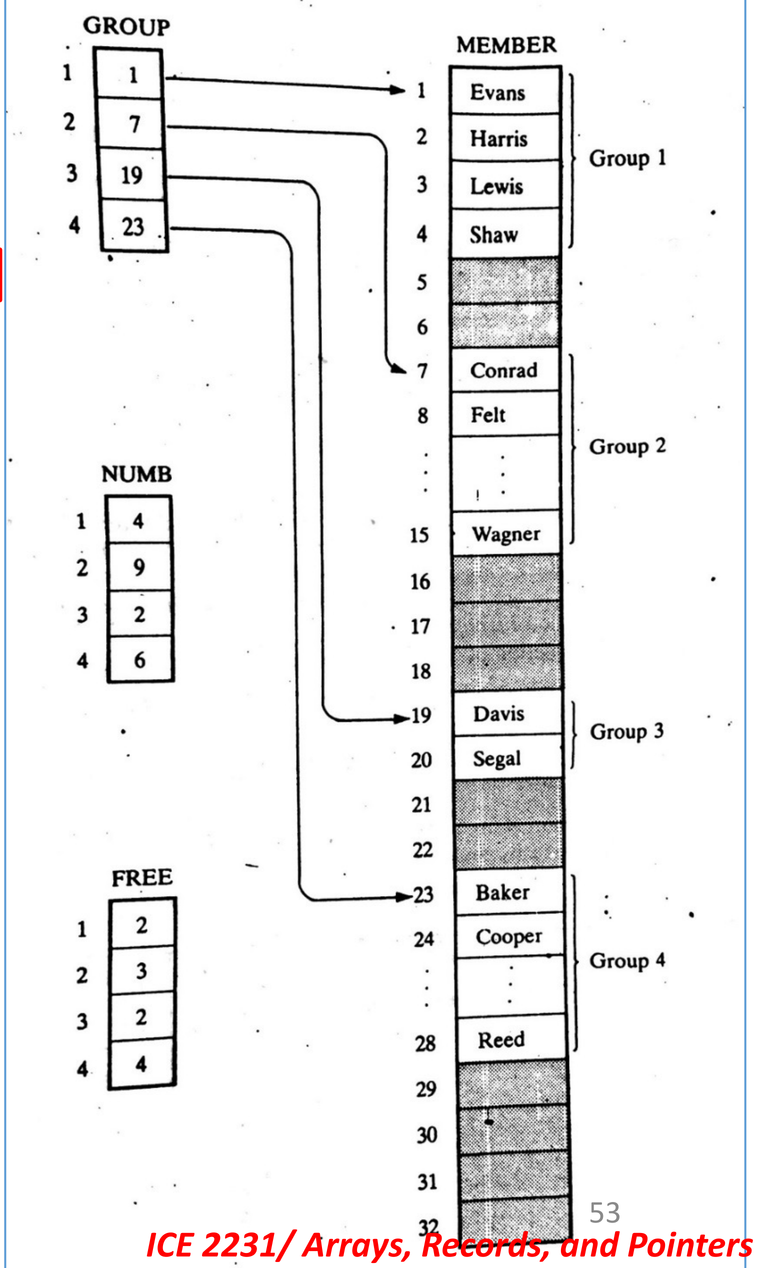
FREE[2]=GROUP[2+1]-GROUP[2]-NUMB[2]

= 19-7-9

=3

For GROUP 3?

Try now



RECORDS

- ✓ A ***record*** is a collection of related data items, each of which is called a field or attribute, and
- ✓ a ***file*** is a collection or similar records.
- ✓ Although, a ***record*** is a collection of data items, it differs from a linear array in the following ways..............
    - ➢ A record may be a collection of nonhomogeneous data;
    - ➢ The data items in a record are indexed by attribute names, so there may not be a natural ordering of its elements.

RECORDS: Structure Example

1. Newborn
    2. Name
    2. Sex
    2. Birthday
        3. Month
        3. Day
        3. Year
    2. Father
        3. Name
        3. Age
    2. Mother
        3. Name
        3. Age

Under the relationship of group item to sub- item, the data items in a record form a hierarchical structure which can be described by mean of “Level” numbers

Name	Sex	Birthday			Father		Mother	
					Name	Age	Name	Age

Indexing Items in a Record

- ✓ Suppose we want to access some data item in a record.
- ✓ We can not simply write the data name of the item since the same may appear in different places in the record. For example.....

1. Newborn
    2. Name
    2. Sex
    2. Birthday
        3. Month
        3. Day
        3. Year
    2. Father
        3. Name
        3. Age
    2. Mother
        3. Name
        3. Age

- ➢ In order to specify a particular item,
    - ❖ we may have to *qualify* the name by using appropriate group item names in the structure.
    - ❖ This *qualification* is indicated by using decimal points (periods) to separate group items from subitems.
    - ❖ Example: Newborn.Father.Age or Father.Age

Fully qualified reference

Indexing Items in a Record

1. Newborn
    2. Name
    2. Sex
    2. Birthday
        3. Month
        3. Day
        3. Year
    2. Father
        3. Name
        3. Age
    2. Mother
        3. Name
        3. Age

→

1. Newborn(20)
    2. Name
    2. Sex
    2. Birthday
        3. Month
        3. Day
        3. Year
    2. Father
        3. Name
        3. Age
    2. Mother
        3. Name
        3. Age

Newborn is defined to be a file with 20 records

✓ The Name of the sixth newborn to be referenced by writing ....

Newborn. Name[6]

✓ The age of the father of the 6th newborn may be referenced by writing.....

Newborn.Father.Age[6]

Representation of RECORDS in memory

Since records may contain nonhomogeneous data, the element of a record can not be stored in an array.

See Example: 4.18, 4.20, 4.21

Teach Yourself with example

Try to understand the SOLVED Problems

NSTART

RSTART

	NAME	ID	NLINK	RLINK
1	Moshi	650		
2	Sakib	422		
3	Riad	704		
4	Liton	462		
5				
6				

NSTART

RSTART

	NAME	ID	NLINK	RLINK
1	Moshi	650		
2	Sakib	422		
3	Riad	704		
4	Liton	462		
5	Mash	632		
6	Fizz	550		