1-d Arrays

Array

- Many applications require multiple data items that have common characteristics
  - In mathematics, we often express such groups of data items in indexed form:
    - $x_1, x_2, x_3, \ldots, x_n$
- Array is a data structure which can represent a collection of data items which have the same data type (float/int/char/…)

Example: Printing Numbers in Reverse

3 numbers

```
int a, b, c;
scanf(“%d”, &a);
scanf(“%d”, &b);
scanf(“%d”, &c);
printf(“%d  ”, c);
printf(“%d  ”, b);
printf(“%d  \n”, a);
```

4 numbers

```
int a, b, c, d;
scanf(“%d”, &a);
scanf(“%d”, &b);
scanf(“%d”, &c);
scanf(“%d”, &d);
printf(“%d  ”, d);
printf(“%d  ”, c);
printf(“%d  ”, b);
printf(“%d  \n”, a);
```

The Problem

- Suppose we have 10 numbers to handle
- Or 20
- Or 100
- Where do we store the numbers ? Use 100 variables ??
- How to tackle this problem?
- Solution:
  - Use arrays

Printing in Reverse Using Arrays

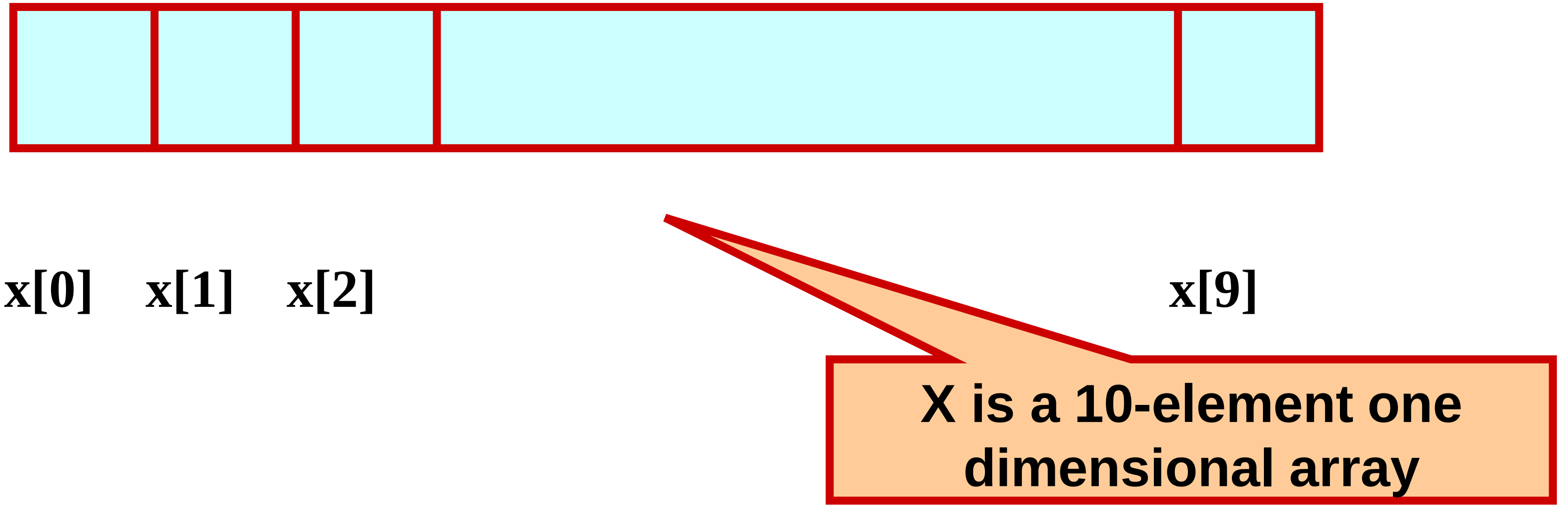
```
void main()
{
    int n, A[100], i;
    printf(“How many numbers to read? “);
    scanf(“%d”, &n);
    for (i = 0; i < n; ++i)
        scanf(“%d”, &A[i]);
    for (i = n -1; i >= 0; --i)
        printf(“%d  ”, A[i]);
    printf(“\n”);
}
```

Using Arrays

- All the data items constituting the group share the same name

```
int  x[10];
```

- Individual elements are accessed by specifying the index



X is a 10-element one dimensional array

A first example

```
void main()
{
  int i;
  int data[10];
  for (i=0; i<10; i++) data[i]= i;
  i=0;
  while (i<10)
  {
    printf("Data[%d] = %d\n", i, data[i]);
    i++;
  }
}
```

“data refers to a block of 10 integer variables, data[0], data[1], …, data[9]

The result

Array size should be a constant

```
void main()
{
  int i;
  int data[10];
  for (i=0; i<10; i++) data[i]= i;
  i=0;
  while (i<10)
  {
    printf("Data[%d] = %d\n", i, data[i]);
    i++;
  }
}
```

Output

```
Data[0] = 0
Data[1] = 1
Data[2] = 2
Data[3] = 3
Data[4] = 4
Data[5] = 5
Data[6] = 6
Data[7] = 7
Data[8] = 8
Data[9] = 9
```

Declaring Arrays

- Like variables, the arrays used in a program must be declared before they are used
- General syntax:

```
type   array-name [size];
```

  - □ type specifies the type of element that will be contained in the array (int, float, char, etc.)
  - □ size is an integer constant which indicates the maximum number of elements that can be stored inside the array

```
int   marks[5];
```

  - □ marks is an array that can store a maximum of 5 integers

- Examples:

```
int  x[10];
char  line[80];
float  points[150];
char  name[35];
```

- If we are not sure of the exact size of the array, we can define an array of a large size

```
int   marks[50];
```

though in a particular run we may only be using, say, 10 elements

Accessing Array Elements

- A particular element of the array can be accessed by specifying two things:
  - □ Name of the array
  - □ Index (relative position) of the element in the array
- In C, the index of an array starts from zero
- Example:
  - □ An array is defined as   int x[10];
  - □ The first element of the array x can be accessed as x[0], fourth element as x[3], tenth element as x[9], etc.

Contd.

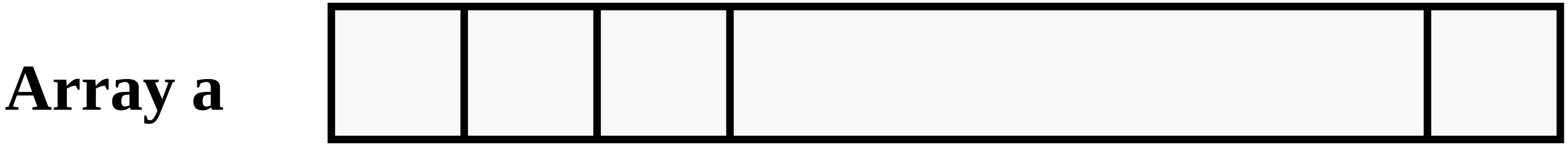
- The array index must evaluate to an integer between 0 and n-1 where n is the maximum number of elements possible in the array

```
a[x+2] = 25;
b[3*x-y] = a[10-x] + 5;
```

- Remember that each array element is a variable in itself, and can be used anywhere a variable can be used (in expressions, assignments, conditions,…)

How is an array stored in memory?

- Starting from a given memory location, the successive array elements are allocated space in consecutive memory locations



Array a

  - x: starting address of the array in memory
  - k: number of bytes allocated per array element
    - a[i] ➔ is allocated memory location at address x + i*k

Storage

```
void main()
{
  int i;
  int data[10];
  for(i=0; i<10; i++)
  printf("&Data[%d] = %u\n", i, &data[i]);
}
```

Output

```
&Data[0] = 3221224480
&Data[1] = 3221224484
&Data[2] = 3221224488
&Data[3] = 3221224492
&Data[4] = 3221224496
&Data[5] = 3221224500
&Data[6] = 3221224504
&Data[7] = 3221224508
&Data[8] = 3221224512
&Data[9] = 3221224516
```

Initialization of Arrays

- General form:

```
type   array_name[size]  =  { list of values };
```

- Examples:

```
int  marks[5] = {72, 83, 65, 80, 76};
char  name[4] = {‘A’, ‘m’, ‘i’, ‘t’};
```

- The size may be omitted. In such cases the compiler automatically allocates enough space for all initialized elements

```
int   flag[ ] = {1, 1, 1, 0};
char  name[ ] = {‘A’, ‘m’, ‘i’, ‘t’};
```

How to read the elements of an array?

- By reading them one element at a time

```
        for  (j=0; j<25; j++)
            scanf  (“%f”, &a[j]);
```

- The ampersand (&) is necessary
- The elements can be entered all in one line or in different lines

A Warning

- In C, while accessing array elements, array bounds are not checked
- Example:

```
int   marks[5];
:
:
marks[8] = 75;
```

  - The above assignment would not necessarily cause an error
  - Rather, it may result in unpredictable program results

Reading into an array

```
void main()
{
   const int MAX_SIZE = 100;
   int i, size;
   float marks[MAX_SIZE];
   float total;
   scanf("%d",&size);
   for (i=0, total=0; i<size; i++)
   {
      scanf("%f",&marks[i]);
      total = total + marks[i];
    }
  printf("Total = %f \n Avg = %f\n", total,
total/size);
}
```

Output

```
4
2.5
3.5
4.5
5
Total = 15.500000
 Avg = 3.875000
```

How to print the elements of an array?

- By printing them one element at a time

```
for  (j=0; j<25; j++)
    printf  (“\n %f”, a[j]);
```

  - The elements are printed one per line

```
printf  (“\n”);
for  (j=0; j<25; j++)
    printf (“ %f”, a[j]);
```

  - The elements are printed all in one line (starting with a new line)

How to copy the elements of one array to another?

- By copying individual elements

```
for  (j=0; j<25; j++)
     a[j] = b[j];
```

- The element assignments will follow the rules of assignment expressions
- Destination array must have sufficient size

Example 1: Find the minimum of a set of 10 numbers

```
void main()
{
    int  a[10], i, min;

    for  (i=0; i<10; i++)
        scanf (“%d”, &a[i]);

    min = a[0];
    for  (i=1; i<10; i++)
    {
        if  (a[i] < min)
            min = a[i];
    }
    printf (“\n Minimum is %d”, min);
}
```

Alternate Version 1

Change only one line to change the problem size

```
const int size = 10;

void main()
{
    int  a[size], i, min;

    for  (i=0; i<size; i++)
        scanf (“%d”, &a[i]);

    min = a[0];
    for  (i=1; i<size; i++)
    {
        if  (a[i] < min)
            min = a[i];
    }
    printf (“\n Minimum is %d”, min);
}
```

Alternate Version 2

Change only one line to change the problem size

Used #define macro

```
#define size 10

void main()
{
    int  a[size], i, min;

    for  (i=0; i<size; i++)
        scanf (“%d”, &a[i]);

    min = a[0];
    for  (i=1; i<size; i++)
    {
        if  (a[i] < min)
            min = a[i];
    }
    printf (“\n Minimum is %d”, min);
}
```

#define macro

- #define X Y
- Preprocessor directive
- Compiler will first replace all occurrences of string X with string Y in the program, then compile the program
- Similar effect as read-only variables (const), but no storage allocated
- We prefer you use const instead of #define

Alternate Version 3

Define an array of large size and use only the required number of elements

```
void main()
{
    int  a[100], i, min, n;

    scanf (“%d”, &n);   /* Number of elements */
    for  (i=0; i<n; i++)
        scanf (“%d”, &a[i]);

    min = a[0];
    for  (i=1; i<n; i++)
    {
        if  (a[i] < min)
            min = a[i];
    }
    printf (“\n Minimum is %d”, min);
}
```

Example 2: Computing cgpa

Handling two arrays at the same time

```
const int  nsub = 6;

void main()
{
    int  grade_pt[nsub], cred[nsub], i,
           gp_sum=0, cred_sum=0;
    double gpa;

    for  (i=0; i<nsub; i++)
        scanf (“%d %d”, &grade_pt[i], &cred[i]);

    for  (i=0; i<nsub; i++)
    {
        gp_sum += grade_pt[i] * cred[i];
        cred_sum += cred[i];
    }
    gpa = ((float) gp_sum) / cred_sum;
    printf (“\n Grade point average:  is %.2lf”, gpa);
}
```

Example: Binary Search

- Searching for an element k in a sorted array A with n elements
- Idea:
  - Choose the middle element A[n/2]
  - If k == A[n/2], we are done
  - If k < A[n/2], search for k between A[0] and A[n/2 -1]
  - If k > A[n/2], search for k between A[n/2 + 1] and A[n-1]
  - Repeat until either k is found, or no more elements to search
- Requires less number of comparisons than linear search in the worst case ($\log_2 n$ instead of n)

```
void main() {
    int A[100], n, k, i, mid, low, high;
    scanf(“%d %d”, &n, &k);
    for (i=0; i<n; ++i) scanf(“%d”, &A[i]);
    low = 0; high = n – 1; mid = low + (high – low)/2;
    while (high >= low) {
          printf(“low = %d, high = %d, mid = %d, A[%d] = %d\n”,
     low, high, mid, mid, A[mid]);
          if (A[mid] == k) {
              printf(“%d is found\n”, k);
              break;
          }
          if (k < A[mid]) high = mid – 1;
          else low = mid + 1;
          mid = low + (high – low)/2;
    }
   If (high < low) printf(“%d is not found\n”, k);
}
```

Output

```
8  21
9  11  14  17  19  20  23  27
low = 0, high = 7, mid = 3, A[3] = 17
low = 4, high = 7, mid = 5, A[5] = 20
low = 6, high = 7, mid = 6, A[6] = 23
21 is not found
```

```
8 14
9 11 14 17 19 20 23 27
low = 0, high = 7, mid = 3, A[3] = 17
low = 0, high = 2, mid = 1, A[1] = 11
low = 2, high = 2, mid = 2, A[2] = 14
14 is found
```

Example: Selection Sort

- Sort the elements of an array A with n elements in ascending order
- Basic Idea:
  - □ Find the min of the n elements, swap it with A[0] (so min is at A[0] now)
  - □ Now find the min of the remaining n-1 elements, swap it with A[1] (so 2nd min is at A[1] now)
  - □ Continue until no more elements left

```
void main() {
    int A[100], n, i, j, k, min, pos, temp;
    scanf(“%d”, &n);
    for (i=0; i<n; ++i) scanf(“%d”, &A[i]);
    for (i = 0; i < n - 1; ++i) {
         min = A[i]; pos = i;
         for (j = i + 1; j < n; ++j) {
             if (A[j] < min) {
                  min = A[j];
                  pos = j;
             }
         }
        temp = A[i];
        A[i] = A[pos];
        A[pos] = temp;
        for (k=0; k<n; ++k) printf(“%d  ”, A[k]);
        printf(“\n”);
    }
}
```

Output

```
6
7 12 5 15 17 9
5  12  7  15  17  9
5  7  12  15  17  9
5  7  9  15  17  12
5  7  9  12  17  15
5  7  9  12  15  17
```

```
8
9 8 7 6 5 4 3 2
2  8  7  6  5  4  3  9
2  3  7  6  5  4  8  9
2  3  4  6  5  7  8  9
2  3  4  5  6  7  8  9
2  3  4  5  6  7  8  9
2  3  4  5  6  7  8  9
2  3  4  5  6  7  8  9
```

Things you cannot do

- You cannot
  - use = to assign one array variable to another

    ```
    a = b;   /* a and b are arrays */
    ```

  - use == to directly compare array variables

    ```
    if  (a = = b)  ………..
    ```

  - directly scanf or printf arrays

    ```
    printf (“……”, a);
    ```

Character Arrays and Strings

```
char C[8] = { 'a', 'b', 'h', 'i', 'j', 'i', 't', '\0' };
```

- C[0] gets the value 'a', C[1] the value 'b', and so on. The last (7th) location receives the null character ‘\0’
- Null-terminated (last character is ‘\0’) character arrays are also called strings
- Strings can be initialized in an alternative way. The last declaration is equivalent to:

```
char C[8] = "abhijit";
```

- The trailing null character is missing here. C automatically puts it at the end if you define it like this
- Note also that for individual characters, C uses single quotes, whereas for strings, it uses double quotes

Reading strings: %s format

```
void main()
{
    char name[25];
    scanf("%s", name);
    printf("Name = %s \n", name);
}
```

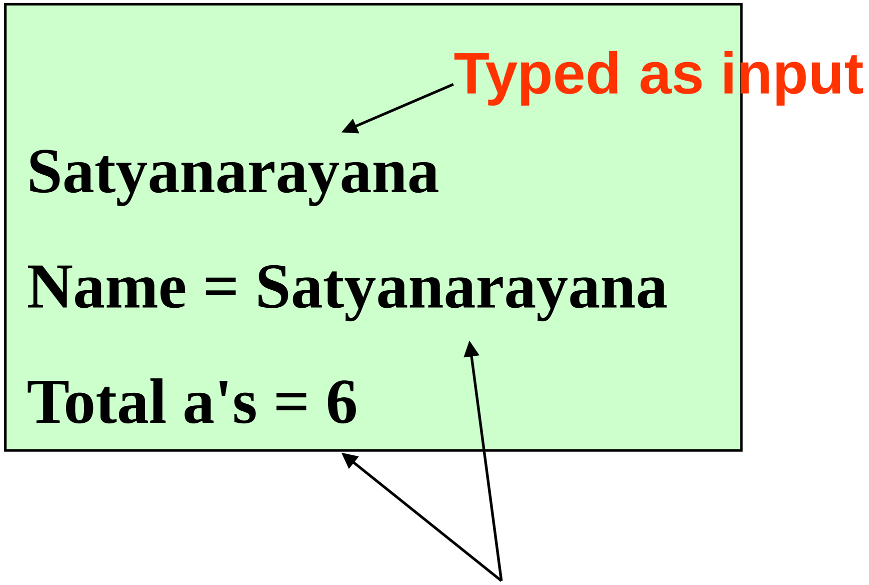
%s reads a string into a character array given the array name or start address.

It ends the string with ‘\0’

An example

```
void main()
{
  #define SIZE 25
  int i, count=0;
  char name[SIZE];
  scanf("%s", name);
  printf("Name = %s \n", name);
  for (i=0; name[i]!='\0'; i++)
    if (name[i] == 'a') count++;
  printf("Total a's = %d\n", count);
}
```

Seen on screen



```
Satyanarayana

Name = Satyanarayana

Total a's = 6
```

Printed by program

Note that character strings read in %s format end with ‘\0’

Palindrome Checking

```
void main()
{
   const int SIZE = 25;
   int i, flag, count=0;
   char name[SIZE];
   scanf("%s", name);     /* Read Name */
   for (i=0; name[i]!='\0'; i++);    /* Find Length of String */
   printf("Total length = %d\n",i);
   count=i;  flag = 0;
   /* Loop below checks for palindrome  by comparison*/
   for(i=0; i<count; i++) if (name[i]!=name[count-i-1]) flag = 1;
   if (flag ==0) printf ("%s is a Palindrome\n", name);
   else printf("%s is NOT a Palindrome\n", name);
}
```

Some Exercises

1. **Write a C program that reads an integer n and stores the first n Fibonacci numbers in an array.**
2. **Write a C program that reads an integer n and uses an array to efficiently find out the first n prime numbers.**
3. **Read in an integer n, read in n integers and print the integer with the highest frequency.**
4. **Read in an integer n, read in n numbers and find out the mean, median and mode.**
5. **Read in two names and compare them and print them in lexicographic (dictionary) order.**
6. **Read in an integer n, read in n names and print the last name when compared in lexicographic order.**

2-d Arrays

Two Dimensional Arrays

- We have seen that an array variable can store a list of values
- Many applications require us to store a table of values

	Subject 1	**Subject 2**	**Subject 3**	**Subject 4**	**Subject 5**
Student 1	75	82	90	65	76
Student 2	68	75	80	70	72
Student 3	88	74	85	76	80
Student 4	50	65	68	40	70

Contd.

- The table contains a total of 20 values, five in each line
  - The table can be regarded as a matrix consisting of four rows and five columns
- C allows us to define such tables of items by using two-dimensional arrays

Declaring 2-D Arrays

- General form:

```
type   array_name [row_size][column_size];
```

- Examples:

```
int  marks[4][5];
float  sales[12][25];
double  matrix[100][100];
```

Initializing 2-d arrays

- int a[2][3] = {1,2,3,4,5,6};
- int a[2][3] = {{1,2,3}, {4,5,6}};
- int a[][3]   = {{1,2,3}, {4,5,6}};

All of the above will give the 2x3 array

```
 1   2   3
4    5   6
```

Accessing Elements of a 2-d Array

- Similar to that for 1-d array, but use two indices
  - First indicates row, second indicates column
  - Both the indices should be expressions which evaluate to integer values (within range of the sizes mentioned in the array declaration)
- Examples:

```
x[m][n] = 0;
c[i][k] += a[i][j] * b[j][k];
a = sqrt (a[j*3][k]);
```

Example

```
int a[3][5];
```

A two-dimensional array of 15 elements

Can be looked upon as a table of 3 rows and 5 columns

	col0	col1	col2	col3	col4
row0	a[0][0]	a[0][1]	a[0][2]	a[0][3]	a[0][4]
row1	a[1][0]	a[1][1]	a[1][2]	a[1][3]	a[1][4]
row2	a[2][0]	a[2][1]	a[2][2]	a[2][3]	a[2][4]

How is a 2-d array is stored in memory?

- Starting from a given memory location, the elements are stored row-wise in consecutive memory locations (row-major order)
    - x: starting address of the array in memory
    - c: number of columns
    - k: number of bytes allocated per array element
  - □ a[i][j] ➔ is allocated memory location at address $x + (i * c + j) * k$

a[0]0] a[0][1] a[0]2] a[0][3] a[1][0] a[1][1] a[1][2] a[1][3] a[2][0] a[2][1] a[2][2] a[2][3]

Row 0 **Row 1** **Row 2**

Array Addresses

```
int main()
{
 int a[3][5];
 int i,j;

 for (i=0; i<3;i++)
 {
   for (j=0; j<5; j++) printf("%u\n", &a[i][j]);
   printf("\n");
 }
 return 0;
}
```

Output

```
3221224480
3221224484
3221224488
3221224492
3221224496

3221224500
3221224504
3221224508
3221224512
3221224516

3221224520
3221224524
3221224528
3221224532
3221224536
```

More on Array Addresses

```
int main()
{
  int a[3][5];
  printf("a = %u\n", a);
  printf("&a[0][0] = %u\n", &a[0][0]);
  printf("&a[2][3] = %u\n", &a[2][3]);
  printf("a[2]+3 = %u\n", a[2]+3);
  printf("*(a+2)+3 = %u\n", *(a+2)+3);
  printf("*(a+2) = %u\n", *(a+2));
  printf("a[2] = %u\n", a[2]);
  printf("&a[2][0] = %u\n", &a[2][0]);
  printf("(a+2) = %u\n", (a+2));
  printf("&a[2] = %u\n", &a[2]);
  return 0;
}
```

Output

```
a = 3221224480
&a[0][0] = 3221224480
&a[2][3] = 3221224532
a[2]+3 = 3221224532
*(a+2)+3 = 3221224532
*(a+2) = 3221224520
a[2] = 3221224520
&a[2][0] = 3221224520
(a+2) = 3221224520
&a[2] = 3221224520
```

How to read the elements of a 2-d array?

- By reading them one element at a time

```
for  (i=0; i<nrow; i++)
    for  (j=0; j<ncol; j++)
        scanf  (“%f”, &a[i][j]);
```

- The ampersand (&) is necessary
- The elements can be entered all in one line or in different lines

How to print the elements of a 2-d array?

- By printing them one element at a time

```
            for  (i=0; i<nrow; i++)
               for  (j=0; j<ncol; j++)
                  printf  (“\n %f”, a[i][j]);
```

  - □ The elements are printed one per line

```
 for  (i=0; i<nrow; i++)
               for  (j=0; j<ncol; j++)
                  printf  (“%f”, a[i][j]);
```

  - □ The elements are all printed on the same line

Contd.

```
for  (i=0; i<nrow; i++)
{
    printf  (“\n”);
    for  (j=0; j<ncol; j++)
        printf (“%f   ”, a[i][j]);
 }
```

- The elements are printed nicely in matrix form

Example: Matrix Addition

```
int main()
{
   int  a[100][100], b[100][100],
            c[100][100], p, q, m, n;

   scanf (“%d %d”, &m, &n);

   for  (p=0; p<m; p++)
      for  (q=0; q<n; q++)
        scanf (“%d”, &a[p][q]);

   for  (p=0; p<m; p++)
      for  (q=0; q<n; q++)
        scanf (“%d”, &b[p][q]);
```

```
   for  (p=0; p<m; p++)
      for  (q=0; q<n; q++)
         c[p][q] = a[p][q] + b[p][q];

   for  (p=0; p<m; p++)
   {
       printf  (“\n”);
       for  (q=0; q<n; q++)
          printf (“%d   ”, c[p][q]);
    }
   return 0;
}
```