9 Arrays

9.1 INTRODUCTION

So far we have used only the fundamental data types, namely **char, int, float, double** and variations of **int** and **double**. Although these types are very useful, they are constrained by the fact that a variable of these types can store only one value at any given time. Therefore, they can be used only to handle limited amounts of data. In many applications, however, we need to handle a large volume of data in terms of reading, processing and printing. To process such large amounts of data, we need a powerful data type that would facilitate efficient storing, accessing and manipulation of data items. C supports a derived data type known as *array* that can be used for such applications.

An array is a *fixed-size* sequenced collection of elements of the same data type. It is simply a grouping of like-type data. In its simplest form, an array can be used to represent a list of numbers, or a list of names. Some examples where the concept of an array can be used:

- List of temperatures recorded every hour in a day, or a month, or a year.
- List of employees in an organization.
- List of products and their cost sold by a store.
- Test scores of a class of students.
- List of customers and their telephone numbers.
- Table of daily rainfall data.

and so on.

Since an array provides a convenient structure for representing data, it is classified as one of the *data structures* in C. Other data structures include structures, lists, queues and trees. A complete discussion of all data structures is beyond the scope of this text.

As we mentioned earlier, an array is a sequenced collection of related data items that share a common name. For instance, we can use an array name *salary* to represent a *set of salaries* of a group of employees in an organization. We can refer to the individual salaries by writing a number called *index* or *subscript* in brackets after the array name. For example,

```
salary [10]
```

represents the salary of 10^{th} employee. While the complete set of values is referred to as an array, individual values are called *elements*.

The ability to use a single name to represent a collection of items and to refer to an item by specifying the item number enables us to develop concise and efficient programs. For example, we can use a loop construct,

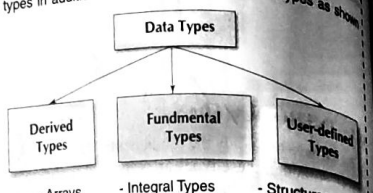
discussed earlier, with the subscript as the control variable to read the entire array, perform calculations, and print out the results.

We can use arrays to represent not only simple lists of values but also tables of data in two, three or more dimensions. In this chapter, we introduce the concept of an array and discuss how to use it to create and apply the following types of arrays.

- One-dimensional arrays
- Two-dimensional arrays
- Multidimensional arrays

Data Structures

C supports a rich set of derived and user-defined data types in addition to a variety of fundamental types as shown below:



Arrays and structures are referred to as *structured data types* because they can be used to represent data values that have a structure of some sort. Structured data types provide an organizational scheme that shows the relationships among the individual elements and facilitate efficient data manipulations. In programming parlance, such data types are known as *data structures*.

In addition to arrays and structures, C supports creation and manipulation of the following data structures:

- Linked Lists
- Stacks
- Queues
- Trees

9.2 ONE-DIMENSIONAL ARRAYS

A list of items can be given one variable name using only one subscript and such a variable is called a *single-subscripted variable* or a *one-dimensional* array. In mathematics, we often deal with variables that are single-subscripted. For instance, we use the equation

$$A = \frac{\sum_{i=1}^{n} x_i}{n}$$

to calculate the average of n values of x. The subscripted variable x_i refers to the ith element of x. In C, single-subscripted variable x_i can be expressed as

x[1], x[2], x[3],.....x[n]

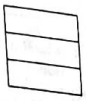
The subscript can begin with number 0. That is

x[0]

is allowed. For example, if we want to represent a set of five numbers, say (35,40,20,57,19), by an array variable **number**, then we may declare the variable **number** as follows

```
int number[5];
```

and the computer reserves five storage locations as shown below:



The values to the array elements can be assigned as follows:

```
number[0] = 35;
number[1] = 40;
number[2] = 20;
number[3] = 57;
number[4] = 19;
```

This would cause the array **number** to store the values as shown below:

number[0]	35
number[1]	40
number[2]	20
number[3]	57
number[4]	19

These elements may be used in programs just like any other C variable. For example, the following are valid statements:

```
a = number[0] + 10;
number[4] = number[0] + number [2];
number[2] = x[5] + y[10];
value[6] = number[i] * 3;
```

The subscripts of an array can be integer constants, integer variables like i, or expressions that yield integers. *C performs no bounds checking and, therefore, care should be exercised to ensure that the array indices are within the declared limits.*

9.3 DECLARATION OF ONE-DIMENSIONAL ARRAYS

Like any other variable, arrays must be declared before they are used so that the compiler can allocate space for them in memory. The general form of array declaration is

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

The *type* specifies the type of element that will be contained in the array, such as **int**, **float**, or **char** and the *size* indicates the maximum number of elements that can be stored inside the array. For example,

```
float height[50];
```

declares the **height** to be an array containing 50 real elements. Any subscripts 0 to 49 are valid. Similarly,

```
int group[10];
```

declares the **group** as an array to contain a maximum of 10 integer constants. Remember:

- Any reference to the arrays outside the declared limits would not necessarily cause an error. Rather, it might result in unpredictable program results.
- The size should be either a numeric constant or a symbolic constant.

The C language treats character strings simply as arrays of characters. The *size* in a character string represents the maximum number of characters that the string can hold. For instance,

```
char name[10];
```

declares the **name** as a character array (string) variable that can hold a maximum of 10 characters. Suppose we read the following string constant into the string variable **name**.

"WELL DONE"

Each character of the string is treated as an element of the array **name** and is stored in the memory as follows:

'W'
'E'
'L'
'L'
' '
'D'
'O'
'N'
'E'
'\0'

When the compiler sees a character string, it terminates it with an additional null character. Thus, the element **name[10]** holds the null character '\0'. *When declaring character arrays, we must allow one extra element space for the null terminator.*

EXAMPLE 9.1 Write a program using a single-subscripted variable to evaluate the following expressions:

$$\text{Total} = \sum_{i=1}^{n} x_2^2$$

The values of x1,x2,....are read from the terminal.

Program in Fig. 9.1 uses a one-dimensional array **x** to read the values and compute the sum of their squares.

```
Program
        main()
          {
            int i ;
            float x[10], value, total ;

        /* . . . . . .READING VALUES INTO ARRAY . . . . . . */

            printf("ENTER 10 REAL NUMBERS\n") ;

            for( i = 0 ; i < 10 ; i++ )
            {
                scanf("%f", &value) ;
                x[i] = value ;
            }
        /* . . . . . .COMPUTATION OF TOTAL . . . . . .*/

            total = 0.0 ;
```

(Contd.)


```
            for( i = 0 ; i < 10 ; i++ )
            total = total + x[i] * x[i] ;

        /*. . . . PRINTING OF x[i] VALUES AND TOTAL . . . */

            printf("\n");
            for( i = 0 ; i < 10 ; i++ )
                printf("x[%2d] = %5.2f\n", i+1, x[i]) ;

            printf("\ntotal = %.2f\n", total) ;
          }
Output
        ENTER 10 REAL NUMBERS


        1.1 2.2 3.3 4.4 5.5 6.6 7.7 8.8 9.9 10.10

            x[ 1] = 1.10
            x[ 2] = 2.20
                x[ 3] = 3.30
                x[ 4] = 4.40
                x[ 5] = 5.50
                x[ 6] = 6.60
                x[ 7] = 7.70
                x[ 8] = 8.80
                x[ 9] = 9.90
                x[10] = 10.10

                Total = 446.86
```

Fig. 9.1 *Program to illustrate one-dimensional array*

NOTE: C99 permits arrays whose size can be specified at run time. See Appendix 'C99 Features'.

9.4 INITIALIZATION OF ONE-DIMENSIONAL ARRAYS

After an array is declared, its elements must be initialized. Otherwise, they will contain "garbage". An array can be initialized at either of the following stages:

- At compile time
- At run time

Compile Time Initialization

We can initialize the elements of arrays in the same way as the ordinary variables when they are declared. The general form of initialization of arrays is:

```
type array-name[size] = { list of values };
```

The values in the list are separated by commas. For example, the statement

```
int number[3] = { 0,0,0 };
```

will declare the variable **number** as an array of size 3 and will assign zero to each element. If the number of values in the list is less than the number of elements, then only that many elements will be initialized. The remaining elements will be set to zero automatically. For instance,

```
float total[5] = {0.0,15.75,-10};
```

will initialize the first three elements to 0.0, 15.75, and –10.0 and the remaining two elements to zero.

The *size* may be omitted. In such cases, the compiler allocates enough space for all initialized elements. For example, the statement

```
int counter[ ] = {1,1,1,1};
```

will declare the **counter** array to contain four elements with initial values 1. This approach works fine as long as we initialize every element in the array.

Character arrays may be initialized in a similar manner. Thus, the statement

```
char name[ ] = {'J','o', 'h', 'n', '\0'};
```

declares the **name** to be an array of five characters, initialized with the string "John" ending with the null character. Alternatively, we can assign the string literal directly as under:

```
char name [ ] = "John";
```

(Character arrays and strings are discussed in detail in Chapter 10.)

Compile time initialization may be partial. That is, the number of initializers may be less than the declared size. In such cases, the remaining elements are initialized to *zero*, if the array type is numeric and *NULL* if the type is char. For example,

```
int number [5] = {10, 20};
```

will initialize the first two elements to 10 and 20 respectively, and the remaining elements to 0. Similarly, the declaration.

```
char city [5] = {'B'};
```

will initialize the first element to 'B' and the remaining four to NULL. It is a good idea, however, to declare the size explicitly, as it allows the compiler to do some error checking.

Remember, however, if we have more initializers than the declared size, the compiler will produce an error. That is, the statement

```
int number [3] = {10, 20, 30, 40};
```

will not work. It is illegal in C.

Run Time Initialization

An array can be explicitly initialized at run time. This approach is usually applied for initializing large arrays. For example, consider the following segment of a C program.

```
        ---------
        ---------
for (i = 0; i < 100; i = i+1)
{
  if   i < 50
       sum[i] = 0.0;          /* assignment statement */
  else
       sum[i] = 1.0;
}
        ---------
        ---------
```

The first 50 elements of the array **sum** are initialized to zero while the remaining 50 elements are initialized to 1.0 at run time.

We can also use a read function such as **scanf** to initialize an array. For example, the statements

```
int x [3];
scanf("%d%d%d", &x[0], &[1], &x[2]);
```

will initialize array elements with the values entered through the keyboard.

EXAMPLE 9.2 Given below is the list of marks obtained by a class of 50 students in an annual examination.

43 65 51 27 79 11 56 61 82 09 25 36 07 49 55 63 74 81 49 37
40 49 16 75 87 91 33 24 58 78 65 56 76 67 45 54 36 63 12 21
73 49 51 19 39 49 68 93 85 59

Write a program to count the number of students belonging to each of following groups of marks: 0–9, 10–19, 20–29,.....,100.

The program coded in Fig. 9.2 uses the array **group** containing 11 elements, one for each range of marks. Each element counts those values falling within the range of values it represents.

For any value, we can determine the correct group element by dividing the value by 10. For example, consider the value 59. The integer division of 59 by 10 yields 5. This is the element into which 59 is counted.

```
Program
  #define   MAXVAL     50
  #define   COUNTER 11
  main()
  {
          float        value[MAXVAL];
          int          i, low, high;
          int   group[COUNTER] = {0,0,0,0,0,0,0,0,0,0,0};
          /* . . . . . .READING AND COUNTING . . . . . .*/
          for( i = 0 ; i < MAXVAL ; i++ )
          {
          /*. . . . . .READING OF VALUES . . . . . */
             scanf("%f", &value[i]) ;
          /*. . . . . .COUNTING FREQUENCY OF GROUPS. . . . . */
             ++ group[ (int) ( value[i]) / 10] ;
          }
          /* . . . .PRINTING OF FREQUENCY TABLE . . . . . .*/
          printf("\n");
          printf(" GROUP    RANGE    FREQUENCY\n\n") ;
          for( i = 0 ; i < COUNTER ; i++ )
          {
                low = i * 10 ;
                if(i == 10)
                   high = 100 ;


                else
                   high = low + 9 ;
                printf(" %2d %3d to %3d %d\n",
                        i+1, low, high, group[i] ) ;
          }
  }
```

(Contd.

```
Output
   43 65 51 27 79 11 56 61 82 09 25 36 07 49 55 63 74
   81 49 37 40 49 16 75 87 91 33 24 58 78 65 56 76 67 (input data)
   45 54 36 63 12 21 73 49 51 19 39 49 68 93 85 59

          GROUP          RANGE          FREQUENCY
            1          0   to   9           2
            2          10  to   19          4
            3          20  to   29          4
            4          30  to   39          5
            5          40  to   49          8
            6          50  to   59          8
            7          60  to   69          7
            8          70  to   79          6
            9          80  to   89          4
            10         90  to   99          2
            11         100 to   100         0
```

Fig. 9.2 *Program for frequency counting*

Note that we have used an initialization statement.

```
int group [COUNTER] = {0,0,0,0,0,0,0,0,0,0};
```

which can be replaced by

```
int group [COUNTER] = {0};
```

This will initialize all the elements to zero.

Searching and Sorting

Searching and sorting are the two most frequent operations performed on arrays. Computer Scientists have devised several data structures and searching and sorting techniques that facilitate rapid access to data stored in lists.

Sorting is the process of arranging elements in the list according to their values, in ascending or descending order. A sorted list is called an *ordered list*. Sorted lists are especially important in list searching because they facilitate rapid search operations. Many sorting techniques are available. The three simple and most important among them are:

- Bubble sort
- Selection sort
- Insertion sort

Other sorting techniques include Shell sort, Merge sort and Quick sort.

Searching is the process of finding the location of the specified element in a list. The specified element is often called the *search key*. If the process of searching finds a match of the search key with a list element value, the search said to be successful; otherwise, it is unsuccessful. The two most commonly used search techniques are:

- Sequential search
- Binary search

A detailed discussion on these techniques is beyond the scope of this text. Consult any good book on data structures and algorithms.

EXAMPLE 9.3 Write a program for sorting the elements of an array in descending order.

1. Set the size n of an array.
2. Store n elements in the array.
3. Read and store elements of the array in descending order.
4. Print the elements of array in descending order.

Figure 9.3 gives a program to implement this algorithm.


```
Program
#include <stdio.h>
#include <conio.h>
void main()
{
    int *arr,temp,i,j,n;
    clrscr();
    printf("Enter the number of elements in the array:");
    scanf("%d",&n);
    arr=(int*)malloc(sizeof(int)*n);
    for(i=0;i<n;i++)
    {
    printf("Enter a number:");
    scanf("%d",&arr[i]);
    }
    for(i=0;i<n;i++)
    {
            for(j=i+1;j<n;j++)
            {
                    if(arr[i]<arr[j])
                    {
                            temp=arr[i];
                            arr[i]=arr[j];
                            arr[j]=temp;
                    }
            }
    }
printf("Elements of array in descending order are:\n");
            for(i=0;i<n;i++)
                    printf("%d\n",arr[i]);
            getch();
}
Output
Enter the number of elements in the array:5
Enter a number:32
Enter a number:43
Enter a number:23
Enter a number:57
Enter a number:47
Elements of array in descending order are:
57
47
43
32
23
```

Fig. 9.3 *Program to sort the elements of an array in descending order*

EXAMPLE 9.4 Write a program for finding the largest number in an array.

1. Set the size of the array as n.
2. Store n elements in the array.

3. Assign the first element of the array to LARGE.
4. Compare each element in the array with LARGE.
5. If an element of the array is greater then LARGE, then set LARGE=element.
6. Else go to step 4.
7. Repeat this process until it reaches the last element of the array.
8. Print the largest element found in the array.

Figure 9.4 gives a program to implement this algorithm.

```
Program
#include <stdio.h>
#include <conio.h>
void main()
{
    int *arr,i,j,n,LARGE;
    clrscr();
    printf("Enter the number of elements in the array:");
    scanf("%d",&n);
    arr=(int*)malloc(sizeof(int)*n);
    for(i=0;i<n;i++)
    {
            printf("Enter a number:");
            scanf("%d",&arr[i]);
    }
    LARGE=arr[0];
    for(i=1;i<n;i++)
    {
            if(arr[i]>LARGE)
                    LARGE=arr[i];
    }
            printf("The largest number in the array is: %d",LARGE);
    getch();
}
Output
Enter the number of elements in the array:5
Enter a number:32
Enter a number:43
Enter a number:23
Enter a number:57
Enter a number:47
The largest number in the array is:57
```

Fig. 9.4 *Program to find the largest element in an array*

EXAMPLE 9.5 Write a program for removing the duplicate element in an array.

1. Set the size n of an array.
2. Store n elements in the array.
3. Read and store elements of the array in a sorted order.
4. Compare the first element with the next element.
5. If elements are identical, then replace that element by shift complete array.
6. Else start comparing element with the current element.

7. Repeat this process until it reaches the last element of the array.
8. Print the new array without duplicate elements.

A program to implement this is given in Fig. 9.5.

```
Program
#include <stdio.h>
#include <conio.h>
#include <stdlib.h>
int main()
{
int *arr,i,j,n,x,temp;
    clrscr();
    printf("Enter the number of elements in the array:");
    scanf("%d",&n);
    arr=(int*)malloc(sizeof(int)*n);
    for(i=0;i<n;i++)
    {
            printf("Enter a number:");
            scanf("%d",&arr[i]);
    }
    for(i=0;i<n;i++)
    {
            for(j=i+1;j<n;j++)
            {
                    if(arr[i]>arr[j])
                    {
                            temp=arr[i];
                            arr[i]=arr[j];
                            arr[j]=temp;
                    }
            }
    }
    printf("\nElements of array after sorting:");
    for(i=0;i<n;i++)
            printf("\n%d",arr[i]);
    i=0;
    j=1;
    while(i<n)
    {
            if(arr[i]==arr[j])
            {
                    for(x=j;x<n-1;x++)
                            arr[x]=arr[x+1];
                    n--;
            }
            else
            {
                    i++;
                    j++;
            }
    }
```

```
        printf("\nElements of array after removing duplicate elements:");
        for(i=0;i<=n;i++)
                printf("\n%d",arr[i]);
        getch();
}
Output
Enter the number of elements in the array:5
Enter a number:3
Enter a number:3
Enter a number:4
Enter a number:6
Enter a number:4
Elements of array after sorting:
3
3
4
4
6
Elements of array after removing duplicate elements:
3
4
6
```

Fig. 9.5 *Program to sort the elements of an array and removing duplicate elements*

EXAMPLE 9.6 Write a program for finding the desired k^{th} smallest element in an array.

1. Set the size n of an array.
2. Store n elements in the array.
3. Read and store elements of the array in an ascending order.
4. Print the k^{th} elements of sorted array.

A program is given in Fig. 9.6.

```
Program
#include <stdio.h>
#include <conio.h>
void main()
{
    int *arr,i,j,n,temp,k;
    clrscr();
    printf("Enter the number of elements in the array:");
    scanf("%d",&n);
    arr=(int*)malloc(sizeof(int)*n);
    for(i=0;i<n;i++)
    {
        printf("Enter a number:");
        scanf("%d",&arr[i]);
    }
    for(i=0;i<n;i++)
    {
        for(j=i+1;j<n;j++)
```

(*Contd.*)


```
        {
            if(arr[i]>arr[j])
            {
                temp=arr[i];
                arr[i]=arr[j];
                arr[j]=temp;
            }
        }
    }
    printf("\nElements of array after sorting:");
    for(i=0;i<n;i++)
        printf("\n%d",arr[i]);
    printf("\n\nWhich smallest element do you want to determine?");
    scanf("%d",&k);
    if(k<=n)
    printf("\nDesired smallest element is %d.",arr[k-1]);
    else
    printf("Please enter a valid value for finding the particular
smallest element");
    getch();
}
Output
Enter the number of elements in the array:5
Enter a number:33
Enter a number:32
Enter a number:46
Enter a number:68
Enter a number:47
Elements of array after sorting:
32
33
46
47
68
Which smallest element do you want to determine?3
Desired smallest element is 46.
```

Fig. 9.6 *Program to determine K^{th} smallest element in an array*

9.5 TWO-DIMENSIONAL ARRAYS

So far we have discussed the array variables that can store a list of values. There could be situations where a table of values will have to be stored. Consider the following data table, which shows the value of sales of three items by four sales girls:

	Item1	*Item2*	*Item3*
Salesgirl #1	310	275	365
Salesgirl #2	210	190	325
Salesgirl #3	405	235	240
Salesgirl #4	260	300	380

The table contains a total of 12 values, three in each line. We can think of this table as a matrix consisting of four *rows* and three *columns*. Each row represents the values of sales by a particular salesgirl and each column represents the values of sales of a particular item.

In mathematics, we represent a particular value in a matrix by using two subscripts such as v_{ij}. Here v denotes the entire matrix and v_{ij} refers to the value in the i^{th} row and j^{th} column. For example, in the above table v_{23} refers to the value 325.

C allows us to define such tables of items by using two-dimensional arrays. The table discussed above can be defined in C as

v[4][3]

Two-dimensional arrays are declared as follows:

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

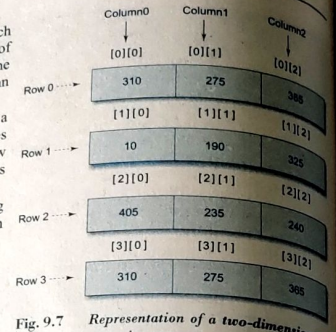


Fig. 9.7 *Representation of a two-dimensional array in memory*

Note that unlike most other languages, which use one pair of parentheses with commas to separate array sizes, C places each size in its own set of brackets.

Two-dimensional arrays are stored in memory, as shown in Fig.9.7. As with the single-dimensional arrays, each dimension of the array is indexed from zero to its maximum size minus one; the first index selects the row and the second index selects the column within that row.

EXAMPLE 9.7 Write a program using a two-dimensional array to compute and print the following information from the table of data discussed above:
(a) Total value of sales by each girl.
(b) Total value of each item sold.
(c) Grand total of sales of all items by all girls.

The program and its output are shown in Fig. 9.8. The program uses the variable **value** in two-dimensions with the index i representing girls and j representing items. The following equations are used in computing the results:

(a) Total sales by m^{th} girl $= \sum_{j=0}^{2} \text{value}[m][j]$ (girl_total[m])

(b) Total value of n^{th} item $= \sum_{i=0}^{3} \text{value}[i][n]$ (item_total[n])

(c) Grand total $= \sum_{i=0}^{3} \sum_{j=0}^{2} \text{value}[i][j]$

$= \sum_{i=0}^{3} \text{girl\_total}[i]$

$= \sum_{j=0}^{2} \text{item\_total}[j]$

Program

```
#define  MAXGIRLS 4
#define  MAXITEMS 3
main()
{
     int   value[MAXGIRLS][MAXITEMS];
     int   girl_total[MAXGIRLS] , item_total[MAXITEMS];
     int   i, j, grand_total;
/*.......READING OF VALUES AND COMPUTING girl_total ...*/
     printf("Input data\n");
     printf("Enter values, one at a time, row-wise\n\n");
     for( i = 0 ; i < MAXGIRLS ; i++ )
     {
          girl_total[i] = 0;
          for( j = 0 ; j < MAXITEMS ; j++ )
          {
               scanf("%d", &value[i][j]);
               girl_total[i] = girl_total[i] + value[i][j];
          }
     }
/*.......COMPUTING item_total.....................*/
     for( j = 0 ; j < MAXITEMS ; j++ )
     {
          item_total[j] = 0;
          for( i =0 ; i < MAXGIRLS ; i++ )
               item_total[j] = item_total[j] + value[i][j];
     }
/*.......COMPUTING grand_total.....................*/
     grand_total = 0;
     for( i =0 ; i < MAXGIRLS ; i++ )
        grand_total = grand_total + girl_total[i];
/* .......PRINTING OF RESULTS.....................*/
     printf("\n GIRLS TOTALS\n\n");
     for( i = 0 ; i < MAXGIRLS ; i++ )
          printf("Salesgirl[%d] = %d\n", i+1, girl_total[i] );
     printf("\n ITEM TOTALS\n\n");
     for( j = 0 ; j < MAXITEMS ; j++ )
          printf("Item[%d] = %d\n", j+1 , item_total[j] );
     printf("\nGrand Total = %d\n", grand_total);
}
```

Output

```
Input data
Enter values, one at a time, row_wise

310 257 365
210 190 325
```

```
405 235 240
260 300 380

GIRLS TOTALS

Salesgirl[1] = 950
Salesgirl[2] = 725
Salesgirl[3] = 880
Salesgirl[4] = 940

ITEM TOTALS

Item[1] = 1185
Item[2] = 1000
Item[3] = 1310

Grand Total = 3495
```

Fig. 9.8 *Illustration of two-dimensional arrays*

EXAMPLE 9.8 Write a program to compute and print a multiplication table for numbers 1 to 5 as shown below:

	1	2	3	4	5
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	.	.	.
4	4	8	.	.	.
5	5	10	.	.	25

The program shown in Fig. 9.9 uses a two-dimensional array to store the table values. Each value is calculated using the control variables of the nested for loops as follows:

product[i] [j] = row * column

where i denotes rows and j denotes columns of the product table. Since the indices i and j range from 0 to 4, we have introduced the following transformation:

row = i+1
column = j+1

```
Program
        #define     ROWS        5
        #define     COLUMNS     5
        main()
        {
                int row, column, product[ROWS][COLUMNS] ;
                int i, j ;
                printf(" MULTIPLICATION TABLE\n\n") ;
                printf(" ") ;
                for( j = 1 ; j <= COLUMNS ; j++ )
                   printf("%4d" , j ) ;
                printf("\n") ;
                printf("-------------------------\n");
```

(Contd.)


```
                for( i = 0 ; i < ROWS ; i++ )
                {
                        row = i + 1 ;
                        printf("%2d |", row) ;
                        for( j = 1 ; j <= COLUMNS ; j++ )
                        {
                           column = j ;
                           product[i][j] = row * column ;
                           printf("%4d", product[i][j] ) ;
                        }
                        printf("\n") ;
                }
        }
```

Output

```
MULTIPLICATION TABLE
    1   2   3   4   5
1 | 1   2   3   4   5
2 | 2   4   6   8   10
3 | 3   6   9   12  15
4 | 4   8   12  16  20
5 | 5   10  15  20  25
```

Fig. 9.9 *Program to print multiplication table using two-dimensional array*

9.6 INITIALIZING TWO-DIMENSIONAL ARRAYS

Like the one-dimensional arrays, two-dimensional arrays may be initialized by following their declaration with a list of initial values enclosed in braces. For example,

```
int table[2][3] = { 0,0,0,1,1,1};
```

initializes the elements of the first row to zero and the second row to one. The initialization is done row by row. The above statement can be equivalently written as

```
int table[2][3] = {{0,0,0}, {1,1,1}};
```

by surrounding the elements of the each row by braces.

We can also initialize a two-dimensional array in the form of a matrix as shown below:

```
int table[2][3] = {
                    {0,0,0},
                    {1,1,1}
                  };
```

Note the syntax of the above statements. Commas are required after each brace that closes off a row, except in the case of the last row.

When the array is completely initialized with all values, explicitly, we need not specify the size of the first dimension. That is, the statement

```
int table [ ] [3] = {
                      { 0, 0, 0},
                      { 1, 1, 1}
                    };
```

is permitted.

If the values are missing in an initializer, they are automatically set to zero. For instance, the statement

```
int table[2][3] = {
                    {1,1},
                    {2}
                  };
```

will initialize the first two elements of the first row to one, the first element of the second row to two, and all other elements to zero.

When all the elements are to be initialized to zero, the following short-cut method may be used.

```
int m[3][5] = { {0}, {0}, {0}};
```

The first element of each row is explicitly initialized to zero while other elements are automatically initialized to zero. The following statement will also achieve the same result:

```
int m [3] [5] = { 0, 0};
```

EXAMPLE 9.9 A survey to know the popularity of four cars (Ambassador, Fiat, Dolphin and Maruti) was conducted in four cities (Bombay, Calcutta, Delhi and Madras). Each person surveyed was asked to give his city and the type of car he was using. The results, in coded form, are tabulated as follows:

M	1	C	2	B	1	D	3	M	2	B	4
C	1	D	3	M	4	B	2	D	1	C	3
D	4	D	4	M	1	M	1	B	3	B	3
C	1	C	1	C	2	M	4	M	4	C	2
D	1	C	2	B	3	M	1	B	1	C	2
D	3	M	4	C	1	D	2	M	3	B	4

Codes represent the following information:

M – Madras	1 – Ambassador
D – Delhi	2 – Fiat
C – Calcutta	3 – Dolphin
B – Bombay	4 – Maruti

Write a program to produce a table showing popularity of various cars in four cities.

A two-dimensional array **frequency** is used as an accumulator to store the number of cars used, under various categories in each city. For example, the element **frequency** [i][j] denotes the number of cars of type j used in city i. The **frequency** is declared as an array of size 5 × 5 and all the elements are initialized to zero.

The program shown in Fig. 9.10 reads the city code and the car code, one set after another, from the terminal. Tabulation ends when the letter X is read in place of a city code.

Program

```
main()
{
    int i, j, car;
    int frequency[5][5] = { {0},{0},{0},{0},{0} };
    char city;
    printf("For each person, enter the city code \n");
    printf("followed by the car code.\n");
    printf("Enter the letter X to indicate end.\n");
/*. . . . . TABULATION BEGINS . . . . . */
    for( i = 1 ; i < 100 ; i++ )
    {
```

(*Contd.*)


```
        scanf("%c", &city );
        if( city == 'X' )
          break;
        scanf("%d", &car );
        switch(city)
        {
                case 'B' : frequency[1][car]++;
                           break;
                case 'C' : frequency[2][car]++;
                           break;
                case 'D' : frequency[3][car]++;
                           break;
                case 'M' : frequency[4][car]++;


                           break;
        }
    }
/*. . . . .TABULATION COMPLETED AND PRINTING BEGINS. . . .*/
    printf("\n\n");
    printf(" POPULARITY TABLE\n\n");
    printf("-------------------------------\n");
    printf("City Ambassador Fiat Dolphin Maruti \n");

    printf("-------------------------------\n");
      for( i = 1 ; i <= 4 ; i++ )
      {
            switch(i) .
            {
                    case 1 : printf("Bombay ") ;
                             break ;
                case 2 : printf("Calcutta ") ;
                             break ;
                case 3 : printf("Delhi ") ;
                             break ;
                case 4 : printf("Madras ") ;
                             break ;
            }
            for( j = 1 ; j <= 4 ; j++ )
              printf("%7d", frequency[i][j] ) ;
            printf("\n") ;
      }
      printf("-------------------------------\n");
    /*. . . . . PRINTING ENDS. . . . . .*/
    }
```

Output

```
For each person, enter the city code
followed by the car code.
Enter the letter X to indicate end.
M 1  C  2  B  1  D 3 M 2 B 4
```

```
C 1 D 3 M 4 B 2 D 1 C 3
D 4 D 4 M 1 M 1 B 3 B 3
C 1 C 1 C 2 M 4 M 4 C 2
D 1 C 2 B 3 M 1 B 1 C 2
D 3 M 4 C 1 D 2 M 3 B 4
```

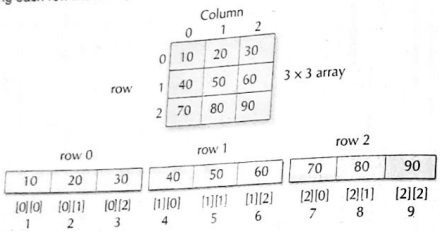
POPULARITY TABLE

City	Ambassador	Fiat	Dolphin	Maruti
Bombay	2	1	3	2
Calcutta	4	5	1	0
Delhi	2	1	3	2
Madras	4	1	1	4

Fig. 9.10 Program to tabulate a survey data

Memory Layout

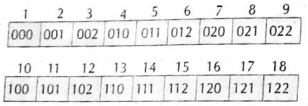
The subscripts in the definition of a two-dimensional array represent rows and columns. This format maps the way that data elements are laid out in the memory. The elements of all arrays are stored contiguously in increasing memory locations, essentially in a single list. If we consider the memory as a row of bytes, with the lowest address on the left and the highest address on the right, a simple array will be stored in memory with the first element at the left end and the last element at the right end. Similarly, a two-dimensional array is stored 'row-wise, starting from the first row and ending with the last row, treating each row like a simple array. This is illustrated below.



Memory Layout

For a multi-dimensional array, the order of storage is that the first element stored has 0 in all its subscripts, the second has all of its subscripts 0 except the far right which has a value of 1 and so on.

The elements of a 2 x 3 x 3 array will be stored as under



The far right subscript increments first and the other subscripts increment in order from right to left. The sequence numbers 1, 2,....., 18 represents the location of that element in the list

9.7 MULTI-DIMENSIONAL ARRAYS

C allows arrays of three or more dimensions. The exact limit is determined by the compiler. The general form of a multi-dimensional array is


```
type array_name[s1][s2][s3]....[sm];
```

where, s_i is the size of the ith dimension. Some examples are:

```
int survey[3][5][12];
float table[5][4][5][3];
```

survey is a three-dimensional array declared to contain 180 integer type elements. Similarly **table** is a four dimensional array containing 300 elements of floating-point type.

The array **survey** may represent a survey data of rainfall during the last three years from January to December in five cities.

If the first index denotes year, the second city and the third month, then the element **survey[2][3][10]** denotes the rainfall in the month of October during the second year in city-3.

Remember that a three-dimensional array can be represented as a series of two-dimensional arrays as shown below:

Year 1

month / city	1	2	.....	12
1				
.				
.				
.				
5				

Year 2

month / city	1	2	.....	12
1				
.				
.				
.				
5				

ANSI C does not specify any limit for array dimension. However, most compilers permit seven to ten dimensions. Some allow even more.

9.8 DYNAMIC ARRAYS

So far, we created arrays at compile time. An array created at compile time by specifying size in the source code has a fixed size and cannot be modified at run time. The process of allocating memory at compile time is known as *static memory allocation* and the arrays that receive static memory allocation are called *static arrays*. This approach works fine as long as we know exactly what our data requirements are.

Consider a situation where we want to use an array that can vary greatly in size. We must guess what will be the largest size ever needed and create the array accordingly. A difficult task in fact! Modern languages like C do not have this limitation. In C it is possible to allocate memory to arrays at run time. This feature is known as *dynamic memory allocation* and the arrays created at run time are called *dynamic* arrays. This effectively postpones the array definition to run time.

10 Character Arrays and Strings

10.1 INTRODUCTION

A string is a sequence of characters that is treated as a single data item. We have used strings in a number of examples in the past. Any group of characters (except double quote sign) defined between double quotation marks is a string constant. Example:

"Man is obviously made to think."

If we want to include a double quote in the string to be printed, then we may use it with a back slash as shown below.

"\" Man is obviously made to think,\" said Pascal."

For example,

```
printf ("\" Well Done !"\");
```

will output the string

" Well Done !"

while the statement

```
printf(" Well Done !");
```

will output the string

Well Done !

Character strings are often used to build meaningful and readable programs. The common operations performed on character strings include:

- Reading and writing strings.
- Combining strings together.
- Copying one string to another.
- Comparing strings for equality.
- Extracting a portion of a string.

In this chapter we shall discuss these operations in detail and examine library functions that implement them.

10.2 DECLARING AND INITIALIZING STRING VARIABLES

C does not support strings as a data type. However, it allows us to represent strings as character arrays. In C, therefore, a string variable is any valid C variable name and is always declared as an array of characters. The general form of declaration of a string variable is:

```
char string_name[ size ];
```

The *size* determines the number of characters in the string_name. Some examples are:

```
char city[10];
char name[30];
```

When the compiler assigns a character string to a character array, it automatically supplies a *null* character ('\0') at the end of the string. Therefore, the *size* should be equal to the maximum number of characters in the string *plus* one.

Like numeric arrays, character arrays may be initialized when they are declared. C permits a character array to be initialized in either of the following two forms:

```
char city [9] = " NEW YORK ";
char city [9]={'N','E','W',' ','Y','O','R','K','\0'};
```

The reason that **city** had to be 9 elements long is that the string NEW YORK contains 8 characters and one element space is provided for the null terminator. Note that when we initialize a character array by listing its elements, we must supply explicitly the null terminator.

C also permits us to initialize a character array without specifying the number of elements. In such cases, the size of the array will be determined automatically, based on the number of elements initialized. For example, the statement

```
char string [ ] = {'G','O','O','D','\0'};
```

defines the array **string** as a five element array.

We can also declare the size much larger than the string size in the initializer. That is, the statement

```
char str[10] = "GOOD";
```

is permitted. In this case, the computer creates a character array of size 10, places the value "GOOD" in it, terminates with the null character, and initializes all other elements to NULL. The storage will look like:

G	O	O	D	\0	\0	\0	\0	\0	\0

However, the following declaration is illegal.

```
char str2[3] = "GOOD";
```

This will result in a compile time error. Also note that we cannot separate the initialization from declaration. That is,

```
char str3[5];
str3 = "GOOD";
```

is not allowed. Similarly,

```
char s1[4] = "abc";
char s2[4];
s2 = s1; /* Error */
```

is not allowed. An array name cannot be used as the left operand of an assignment operator.

Terminating Null Character

You must be wondering, "why do we need a terminating null character?" As we know, a string is not a data type in C, but it is considered a data structure stored in an array. The string is a variable-length structure and is stored in a fixed-length array. The array size is not always the size of the string and most often it is much larger than the string stored in it. Therefore, the last element of the array need not represent the end of the string. We need some way to determine the end of the string data and the null character serves as the "end-of-string" marker.

10.3 READING STRINGS FROM TERMINAL

Using scanf Function

The familiar input function **scanf** can be used with **%s** format specification to read in a string of characters. Example:

```
char address[10]
scanf("%s", address);
```

The problem with the **scanf** function is that it terminates its input on the first white space it finds. A white space includes blanks, tabs, carriage returns, form feeds, and new lines. Therefore, if the following line of text is typed in at the terminal,

NEW YORK

then only the string "NEW" will be read into the array **address**, since the blank space after the word 'NEW' will terminate the reading of string.

The **scanf** function automatically terminates the string that is read with a null character and therefore the character array should be large enough to hold the input string plus the null character. Note that unlike previous **scanf** calls, in the case of character arrays, the ampersand (&) is not required before the variable name.

The **address** array is created in the memory as shown below:

N	E	W	\0	?	?	?	?	?	?
0	1	2	3	4	5	6	7	8	9

Note that the unused locations are filled with garbage.

If we want to read the entire line "NEW YORK", then we may use two character arrays of appropriate sizes. That is,

```
char adr1[5], adr2[5];
scanf("%s %s", adr1, adr2);
```

with the line of text

NEW YORK

will assign the string "NEW" to **adr1** and "YORK" to **adr2**.

EXAMPLE 10.1 Write a program to read a series of words from a terminal using scanf function.

The program shown in Fig. 10.1 reads four words and displays them on the screen. Note that the string 'Oxford Road' is treated as *two words* while the string 'Oxford-Road' as *one word*.

```
Program
        main( )
        {
                char word1[40], word2[40], word3[40], word4[40];

                printf("Enter text : \n");
                scanf("%s %s", word1, word2);
                scanf("%s", word3);
                scanf("%s", word4);

                printf("\n");
                printf("word1 = %s\nword2 = %s\n", word1, word2);
                printf("word3 = %s\nword4 = %s\n", word3, word4);
        }
```

(Cont

```
Output

        Enter text :
        Oxford Road, London M17ED

        word1 = Oxford
        word2 = Road,
        word3 = London
        word4 = M17ED

        Enter text :
        Oxford-Road, London-M17ED United Kingdom
        word1 = Oxford-Road
        word2 = London-M17ED
        word3 = United
        word4 = Kingdom
```

Fig. 10.1 *Reading a series of words using scanf function*

We can also specify the field width using the form %ws in the **scanf** statement for reading a specified number of characters from the input string . Example:

```
scanf("%ws", name);
```

Here, two things may happen.

1. The width w is equal to or greater than the number of characters typed in. The entire string will be stored in the string variable.
2. The width w is less than the number of characters in the string. The excess characters will be truncated and left unread.

Consider the following statements:

```
char name[10];
scanf("%5s", name);
```

The input string RAM will be stored as:

R	A	M	\0	?	?	?	?	?	?
0	1	2	3	4	5	6	7	8	9

The input string KRISHNA will be stored as:

K	R	I	S	H	\0	?	?	?	?
0	1	2	3	4	5	6	7	8	9

Reading a Line of Text

We have seen just now that **scanf** with %s or %ws can read only strings without whitespaces. That is, they cannot be used for reading a text containing more than one word. However, C supports a format specification known as the *edit set conversion code* %[. .] that can be used to read a line containing a variety of characters, including whitespaces. Recall that we have used this conversion code in Chapter 4. For example, the program segment

```
char line [80];
scanf("%[^\n]", line);
printf("%s", line);
```

will read a line of input from the keyboard and display the same on the screen. We would very rarely use this method, as C supports an intrinsic string function to do this job. This is discussed in the next section.

Using *getchar* and *gets* Functions

We have discussed in Chapter 4 as to how to read a single character from the terminal, using the function **getchar**. We can use this function repeatedly to read successive single characters from the input and place them into a character array. Thus, an entire line of text can be read and stored in an array. The reading is terminated when the newline character ('\n') is entered and the null character is then inserted at the end of the string. The **getchar** function call takes the form:

```
char ch;
ch = getchar( );
```

Note that the **getchar** function has no parameters.

EXAMPLE 10.2 Write a program to read a line of text containing a series of words from the terminal.

The program shown in Fig. 10.2 can read a line of text (up to a maximum of 80 characters) into the string **line** using **getchar** function. Every time a character is read, it is assigned to its location in the string **line** and then tested for *newline* character. When the *newline* character is read (signalling the end of line), the reading loop is terminated and the *newline* character is replaced by the null character to indicate the end of character string.

When the loop is exited, the value of the index c is one number higher than the last character position in the string (since it has been incremented after assigning the new character to the string). Therefore the index value c-1 gives the position where the *null* character is to be stored.

```
Program
        #include <stdio.h>
        main( )
        {
           char line[81], character;
           int c;
           c = 0;
           printf("Enter text. Press <Return> at end\n");
           do
           {
           character = getchar();
           line[c] = character;
           c++;
           }
           while(character != '\n');
           c = c - 1;
           line[c] = '\0';
           printf("\n%s\n", line);
        }
Output
        Enter text. Press <Return> at end
        Programming in C is interesting.
        Programming in C is interesting.
        Enter text. Press <Return> at end
        National Centre for Expert Systems, Hyderabad.
        National Centre for Expert Systems, Hyderabad.
```


Fig. 10.2 *Program to read a line of text from terminal*

Another and more convenient method of reading a string of text containing whitespaces is to use the library function **gets** available in the *<stdio.h>* header file. This is a simple function with one string parameter and called as under:

```
gets (str);
```

str is a string variable declared properly. It reads characters into **str** from the keyboard until a new-line character is encountered and then appends a null character to the string. Unlike **scanf**, it does not skip whitespaces. For example the code segment

```
char line [80];
gets (line);
printf ("%s", line);
```

reads a line of text from the keyboard and displays it on the screen. The last two statements may be combined as follows:

```
printf("%s", gets(line));
```

(Be careful not to input more character that can be stored in the string variable used. Since C does not check array-bounds, it may cause problems.)

C does not provide operators that work on strings directly. For instance we cannot assign one string to another directly. For example, the assignment statements.

```
string = "ABC";
string1 = string2;
```

are not valid. If we really want to copy the characters in **string2** into **string1**, we may do so on a character-by-character basis.

EXAMPLE 10.3 Write a program to copy one string into another and count the number of characters copied.

The program is shown in Fig. 10.3. We use a **for** loop to copy the characters contained inside **string2** into the string1. The loop is terminated when the *null* character is reached. Note that we are again assigning a null character to the **string1.**

```
Program
        main( )
        {
           char string1[80], string2[80];
           int i;
           printf("Enter a string \n");
           printf("?");
           scanf("%s", string2);
           for( i=0 ; string2[i] != '\0'; i++)
                 string1[i] = string2[i];
           string1[i] = '\0';
           printf("\n");
           printf("%s\n", string1);
           printf("Number of characters = %d\n", i );
        }
Output
        Enter a string
        ?Manchester
        Manchester
        Number of characters = 10
        Enter a string
        ?Westminster
           Westminster
        Number of characters = 11
```

(*Contd.*)

Fig. 10.3 *Copying one string into another*

10.4 WRITING STRINGS TO SCREEN

Using printf Function

We have used extensively the **printf** function with %s format to print strings to the screen. The format %s can be used to display an array of characters that is terminated by the null character. For example, the statement

```
printf("%s", name);
```

can be used to display the entire contents of the array **name**.

We can also specify the precision with which the array is displayed. For instance, the specification

```
%10.4
```

indicates that the *first four* characters are to be printed in a field width of 10 columns.

However, if we include the minus sign in the specification (e.g., %-10.4s), the string will be printed left-justified. The Example 10.4 illustrates the effect of various %s specifications.

EXAMPLE 10.4 Write a program to store the string "United Kingdom" in the array country and display the string under various format specifications.

The program and its output are shown in Fig. 10.4. The output illustrates the following features of the **%s** specifications.

1. When the field width is less than the length of the string, the entire string is printed.
2. The integer value on the right side of the decimal point specifies the number of characters to be printed.
3. When the number of characters to be printed is specified as zero, nothing is printed.
4. The minus sign in the specification causes the string to be printed left-justified.
5. The specification % .ns prints the first n characters of the string.

```
Program
        main()
        {
           char country[15] = "United Kingdom";
           printf("\n\n");
           printf("*123456789012345*\n");
           printf(" ------ \n");
           printf("%15s\n", country);
           printf("%5s\n", country);
           printf("%15.6s\n", country);
           printf("%-15.6s\n", country);
           printf("%15.0s\n", country);
           printf("%.3s\n", country);
           printf("%s\n", country);
           printf("------ \n");
        }
```

(*Contd.*)

```
Output
        *123456789012345*
        -----
        United Kingdom
        United Kingdom
                United
        United

        Uni
        United Kingdom
        -----
```

Fig. 10.4 *Writing strings using "%s format*

The **printf** on UNIX supports another nice feature that allows for variable field width or precision. For instance

```
printf("%*.*s\n", w, d, string);
```

prints the first **d** characters of the string in the field width of **w**

This feature comes in handy for printing a sequence of characters. Example 10.5 illustrates this.

EXAMPLE 10.4 Write a program using for loop to print the following output:

```
C
CP
CPr
CPro
.....
.....
CProgramming
CProgramming
.....
.....
CPro
CPr
CP
C
```

The outputs of the program in Fig. 10.5, for variable specifications **%12.*s, %.*s,** and **%*.1s** are shown in Fig. 10.6, which further illustrates the variable field width and the precision specifications.

```
Program
        main()
        {
            int c, d;
            char string[] = "CProgramming";
            printf("\n\n");
            printf("------------\n");
            for( c = 0 ; c <= 11 ; c++ )
            {
                d = c + 1;
                printf("|%-12.*s|\n", d, string);
            }
            printf("|————————|\n");
```

(Contd.)


```
            for( c = 11 ; c >= 0 ; c— )
            {
                d = c + 1;
                printf("|%-12.*s|\n", d, string);
            }
            printf("------------\n");
        }
Output
        C
        CP
        CPr
        CPro
        CProg
        CProgr
        CProgra
        CProgram
        CProgramm
        CProgrammi
        CProgrammin
        CProgramming
        CProgramming
        CProgrammin
        CProgrammi
        CProgramm
        CProgram
        CProgra
        CProgr
        CProg
        CPro
        CPr
        CP
        C
```

Fig. 10.5 *Illustration of variable field specifications by printing sequences of characters*

```
          C|          C|          C|
         CP|         CP|          C|
        CPr|        CPr|           C|
       CPro|       CPro|            C|
      CProg|      CProg|             C|
     CProgr|     CProgr|              C|
    CProgra|    CProgra|               C|
   CProgram|   CProgram|                C|
  CProgramm|  CProgramm|                 C|
 CProgrammi| CProgrammi|                  C|
CProgrammin|CProgrammin|                   C|
CProgramming|CProgramming|                  C|
-------------|-------------|-----------------
CProgramming| CProgramming|                  C|
 CProgrammin|  CProgrammin|                 C|
  CProgrammi|   CProgrammi|                C|
   CProgramm|    CProgramm|               C|
    CProgram|     CProgram|              C|
```

(Con

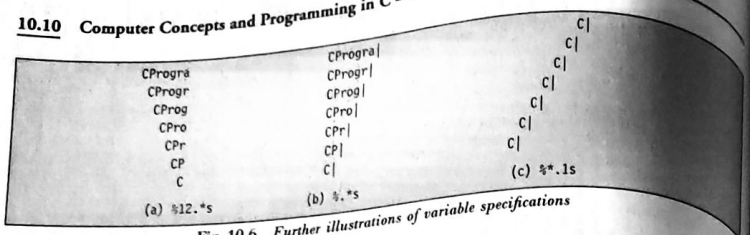


Fig. 10.6 *Further illustrations of variable specifications*

Using putchar and puts Functions

Like **getchar**, C supports another character handling function **putchar** to output the values of character variables. It takes the following form:

```
putchar (ch);
```

The function **putchar** requires one parameter. This statement is equivalent to:

```
printf("%c", ch);
```

We have used **putchar** function in Chapter 5 to write characters to the screen. We can use this function repeatedly to output a string of characters stored in an array using a loop. Example:

```
char name[6] = "PARIS"
for (i=0, i<5; i++)
   putchar(name[i];
putchar('\n');
```

Another and more convenient way of printing string values is to use the function **puts** declared in the header file *<stdio.h>*. This is a one parameter function and invoked as under:

```
puts ( str );
```

where **str** is a string variable containing a string value. This prints the value of the string variable **str** and then moves the cursor to the beginning of the next line on the screen. For example, the program segment

```
char line [80];
gets (line);
puts (line);
```

reads a line of text from the keyboard and displays it on the screen. Note that the syntax is very simple compared to using the **scanf** and **printf** statements.

10.5 ARITHMETIC OPERATIONS ON CHARACTERS

C allows us to manipulate characters the same way we do with numbers. Whenever a character constant or character variable is used in an expression, it is automatically converted into an integer value by the system. The integer value depends on the local character set of the system.

To write a character in its integer representation, we may write it as an integer. For example, if the machine uses the ASCII representation, then,

```
x = 'a';
printf("%d\n",x);
```

will display the number 97 on the screen.

It is also possible to perform arithmetic operations on the character constants and variables. For example,

```
x = 'z'-1;
```


is a valid statement. In ASCII, the value of 'z' is 122 and therefore, the statement will assign the value 121 to the variable x.

We may also use character constants in relational expressions. For example, the expression

```
ch >= 'A' && ch <= 'Z'
```

would test whether the character contained in the variable ch is an upper-case letter.

We can convert a character digit to its equivalent integer value using the following relationship:

```
x = character - '0';
```

where x is defined as an integer variable and **character** contains the character digit. For example, let us assume that the **character** contains the digit '7',

Then,

```
x = ASCII value of '7' – ASCII value of '0'
  = 55 – 48
  = 7
```

The C library supports a function that converts a string of digits into their integer values. The function takes the form

```
x = atoi(string);
```

x is an integer variable and **string** is a character array containing a string of digits. Consider the following segment of a program:

```
number = "1988";
year = atoi(number);
```

number is a string variable which is assigned the string constant "1988". The function **atoi** converts the string "1988" (contained in **number**) to its numeric equivalent 1988 and assigns it to the integer variable **year**. String conversion functions are stored in the header file <std.lib.h>.

EXAMPLE 10.6 Write a program which would print the alphabet set a to z and A to Z in decimal and character form.

The program is shown in Fig. 10.7. In ASCII character set, the decimal numbers 65 to 90 represent upper case alphabets and 97 to 122 represent lower case alphabets. The values from 91 to 96 are excluded using an **if** statement in the **for** loop.

```
Program
        main()
        {
           char c;
           printf("\n\n");
           for( c = 65 ; c <= 122 ; c = c + 1 )
           {
              if( c > 90 && c < 97 )
                 continue;
              printf("|%4d - %c ", c, c);
           }
           printf("|\n");
        }
Output
        | 65 - A | 66 - B | 67 - C | 68 - D | 69 - E | 70 - F
        | 71 - G | 72 - H | 73 - I | 74 - J | 75 - K | 76 - L
```

(Contd

```
| 77 - M| 78 - N| 79 - O| 80 - P| 81 - Q| 82 - R
| 83 - S| 84 - T| 85 - U| 86 - V| 87 - W| 88 - X
| 89 - Y| 90 - Z| 97 - a| 98 - b| 99 - c| 100 - d
|101  - e| 102 - f| 103 - g| 104 - h| 105 - i| 106 - j
|107  - k| 108 - l| 109 - m| 110 - n| 111 - o| 112 - p
|113  - q| 114 - r| 115 - s| 116 - t| 117 - u| 118 - v
|119  - w| 120 - x| 121 - y| 122 - z|
```

Fig. 10.7 *Printing of the alphabet set in decimal and character form*

10.6 PUTTING STRINGS TOGETHER

Just as we cannot assign one string to another directly, we cannot join two strings together by the simple arithmetic addition. That is, the statements such as

```
string3 = string1 + string2;
string2 = string1 + "hello";
```

are not valid. The characters from **string1** and **string2** should be copied into the **string3** one after the other. The size of the array **string3** should be large enough to hold the total characters.

The process of combining two strings together is called *concatenation*. Example 10.7 illustrates the concatenation of three strings.

EXAMPLE 10.7 The names of employees of an organization are stored in three arrays, namely first_name, second_name, and last_name. Write a program to concatenate the three parts into one string to be called name.

The program is given in Fig. 10.8. Three **for** loops are used to copy the three strings. In the first loop, the characters contained in the **first_name** are copied into the variable **name** until the *null* character is reached. The *null* character is not copied; instead it is replaced by a *space* by the assignment statement

```
name[i] = ' ' ;
```

Similarly, the **second_name** is copied into **name**, starting from the column just after the space created by the above statement. This is achieved by the assignment statement

```
name[i+j+1] = second_name[j];
```

If **first_name** contains 4 characters, then the value of **i** at this point will be 4 and therefore the first character from **second_name** will be placed in the *fifth cell* of **name**. Note that we have stored a space in the *fourth cell*.

In the same way, the statement

```
name[i+j+k+2] = last_name[k];
```

is used to copy the characters from **last_name** into the proper locations of **name**.

At the end, we place a null character to terminate the concatenated string **name**. In this example, it is important to note the use of the expressions **i+j+1** and **i+j+k+2**.

Program

```
main()
{
    int i, j, k ;
    char first_name[10] = {"VISWANATH"} ;
    char second_name[10] = {"PRATAP"} ;
    char last_name[10] = {"SINGH"} ;
    char name[30] ;
/* Copy first_name into name */
```

(Contd.)


```
    for( i = 0 ; first_name[i] != '\0' ; i++ )
        name[i] = first_name[i] ;
/* End first_name with a space */
    name[i] = ' ' ;
/* Copy second_name into name */
    for( j = 0 ; second_name[j] != '\0' ; j++ )
    name[i+j+1] = second_name[j] ;
/* End second_name with a space */
    name[i+j+1] = ' ' ;
/* Copy last_name into name */
    for( k = 0 ; last_name[k] != '\0'; k++ )
    name[i+j+k+2] = last_name[k] ;
/* End name with a null character */
    name[i+j+k+2] = '\0' ;
    printf("\n\n") ;
    printf("%s\n", name) ;
}
```

Output

```
VISWANATH PRATAP SINGH
```

Fig. 10.8 *Concatenation of strings*

10.7 COMPARISON OF TWO STRINGS

Once again, C does not permit the comparison of two strings directly. That is, the statements such as

```
if(name1 == name2)
if(name == "ABC")
```

are not permitted. It is therefore necessary to compare the two strings to be tested, character by character. The comparison is done until there is a mismatch or one of the strings terminates into a null character, whichever occurs first. The following segment of a program illustrates this.

```
i=0;
while(str1[i] == str2[i] && str1[i] != '\0'
      && str2[i] != '\0')
  i = i+1;
if (str1[i] == '\0' && str2[i] == '\0')
    printf("strings are equal\n");
  else
    printf("strings are not equal\n");
```

10.8 STRING-HANDLING FUNCTIONS

Fortunately, the C library supports a large number of string-handling functions that can be used to carry out many of the string manipulations discussed so far. Following are the most commonly used string-handling functions.

Function	*Action*
strcat()	concatenates two strings
strcmp()	compares two strings
strcpy()	copies one string over another
strlen()	finds the length of a string

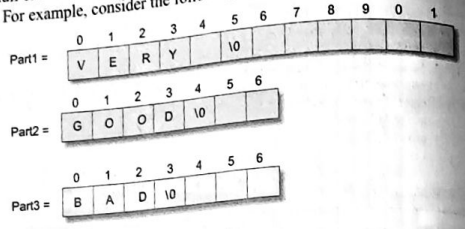
We shall discuss briefly how each of these functions can be used in the processing of strings.

strcat() Function

The **strcat** function joins two strings together. It takes the following form:

```
strcat(string1, string2);
```

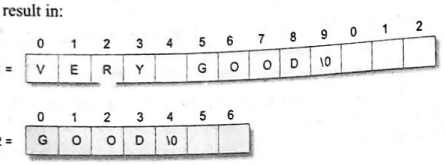
string1 and **string2** are character arrays. When the function **strcat** is executed, **string2** is appended to **string1**. It does so by removing the null character at the end of **string1** and placing **string2** from there. The string at **string2** remains unchanged. For example, consider the following three strings:



Execution of the statement

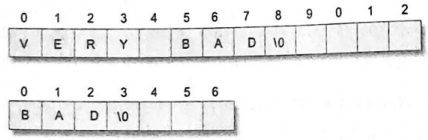
```
strcat(part1, part2);
```

will result in:



while the statement

will result in:



We must make sure that the size of **string1** (to which string2 is appended) is large enough to accommodate the final string.

strcat function may also append a string constant to a string variable. The following is valid:

```
strcat(part1,"GOOD");
```

C permits nesting of **strcat** functions. For example, the statement

```
strcat(strcat(string1,string2), string3);
```

is allowed and concatenates all the three strings together. The resultant string is stored in **string1.**

strcmp() Function

The **strcmp** function compares two strings identified by the arguments and has a value 0 if they are equal. If they are not, it has the numeric difference between the first nonmatching characters in the strings. It takes the form:


```
strcmp(string1, string2);
```

string1 and string2 may be string variables or string constants. Examples are:

```
strcmp(name1, name2);
strcmp(name1, "John");
strcmp("Rom", "Ram");
```

Our major concern is to determine whether the strings are equal; if not, which is alphabetically above. The value of the mismatch is rarely important. For example, the statement

```
strcmp("their", "there");
```

will return a value of –9 which is the numeric difference between ASCII "i" and ASCII "r". That is, "i" minus "r" in ASCII code is –9. If the value is negative, **string1** is alphabetically above **string2**.

strcpy() Function

The strcpy function works almost like a string-assignment operator. It takes the form:

```
strcpy(string1, string2);
```

and assigns the contents of **string2** to **string1**. **string2** may be a character array variable or a string constant. For example, the statement

```
strcpy(city, "DELHI");
```

will assign the string "DELHI" to the string variable **city**. Similarly, the statement

```
strcpy(city1, city2);
```

will assign the contents of the string variable **city2** to the string variable **city1**. The size of the array **city1** should be large enough to receive the contents of **city2.**

strlen() Function

This function counts and returns the number of characters in a string. It takes the form

```
n = strlen(string);
```

Where n is an integer variable, which receives the value of the length of the **string.** The argument may be a string constant. The counting ends at the first null character.

EXAMPLE 10.8 s1, s2, and s3 are three string variables. Write a program to read two string constants into s1 and s2 and compare whether they are equal or not. If they are not, join them together. Then copy the contents of s1 to the variable s3. At the end, the program should print the contents of all the three variables and their lengths.

The program is shown in Fig. 10.9. During the first run, the input strings are "New" and "York". These strings are compared by the statement

```
x = strcmp(s1, s2);
```

Since they are not equal, they are joined together and copied into **s3** using the statement

```
strcpy(s3, s1);
```

The program outputs all the three strings with their lengths.

During the second run, the two strings **s1** and **s2** are equal, and therefore, they are not joined together. In this case all the three strings contain the same string constant "London".

```
Program
        #include <string.h>
        main()
        {   char s1[20], s2[20], s3[20];
```

(Contd.)

```
    int x, l1, l2, l3;
    printf("\n\nEnter two string constants \n");
    printf("?");
    scanf("%s %s", s1, s2);
/*  comparing s1 and s2 */
    x = strcmp(s1, s2);
    if(x != 0)
    {     printf("\n\nStrings are not equal \n");
      strcat(s1, s2); /* joining s1 and s2 */
    }
    else
          printf("\n\nStrings are equal \n");
/*  copying s1 to s3
    strcpy(s3, s1);
/*  Finding length of strings */
    l1 = strlen(s1);
    l2 = strlen(s2);
    l3 = strlen(s3);
/*  output */
    printf("\ns1 = %s\t length = %d characters\n", s1, l1);
    printf("s2 = %s\t length = %d characters\n", s2, l2);
    printf("s3 = %s\t length = %d characters\n", s3, l3);
}
```

Output

```
Enter two string constants
? New York

Strings are not equal
s1 = NewYork length = 7 characters
s2 = York       length = 4 characters
s3 = NewYork length = 7 characters

Enter two string constants
? London London

Strings are equal

s1 = London length = 6 characters
s2 = London length = 6 characters
s3 = London length = 6 characters
```

Fig. 10.9 *Illustration of string handling functions*

Other String Functions

The header file **<string.h>** contains many more string manipulation functions. They might be useful in certain situations.

strncpy

In addition to the function **strcpy** that copies one string to another, we have another function **strncpy** that copies only the left-most n characters of the source string to the target string variable. This is a three-parameter function and is invoked as follows:

```
strncpy(s1, s2, 5);
```

This statement copies the first 5 characters of the source string **s2** into the target string **s1**. Since the first 5 characters may not include the terminating null character, we have to place it explicitly in the 6th position of **s2** as shown below:


```
s1[6] ='\0';
```

...ring s1 contains a proper string.

...of the function **strcmp** is the function **strncmp**. This function has three parameters as illustrated ...n call below:

```
strncmp (s1, s2, n);
```

...s the left-most n characters of **s1** to **s2** and returns.

...they are equal;

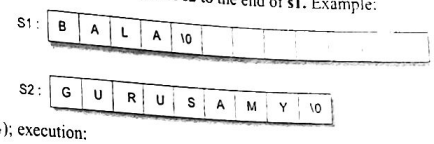
...ive number, if s1 sub-string is less than s2; and

...tive number, otherwise.

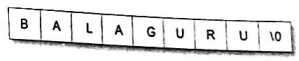
...another concatenation function that takes three parameters as shown below:

```
strncat (s1, s2, n);
```

...will concatenate the left-most n characters of **s2** to the end of **s1**. Example:



...strncat (s1, s2, s4); execution:



...

It ...parameter function that can be used to locate a sub-string in a string. This takes the forms:

```
strstr (s1, s2);
strstr (s1, "ABC");
```

The function **strstr** searches the string **s1** to see whether the string **s2** is contained in **s1**. If yes, the function returns the position of the first occurrence of the sub-string. Otherwise, it returns a NULL pointer. Example.

```
if (strstr (s1, s2) == NULL)
  printf("substring is not found");
else
  printf("s2 is a substring of s1");
```

We also have functions to determine the existence of a character in a string. The function call

```
strchr(s1, 'm');
```

will locate the first occurrence of the character 'm' and the call

```
strrchr(s1, 'm');
```

will locate the last occurrence of the character 'm' in the string **s1**.

Warnings

- When allocating space for a string during declaration, remember to count the terminating null character.
- When creating an array to hold a copy of a string variable of unknown size, we can compute the size required using the expression
  strlen (stringname) +1.
- When copying or concatenating one string to another, we must ensure that the target (destination) string has enough space to hold the incoming characters. Remember that no error message will be available even if this condition is not satisfied. The copying may overwrite the memory and the program may fail in an unpredictable way.
- When we use **strncpy** to copy a specific number of characters from a source string, we must ensure to append the null character to the target string, in case the number of characters is less than or equal to the source string.

10.9 TABLE OF STRINGS

We often use lists of character strings, such as a list of the names of students in a class, list of the names of employees in an organization, list of places, etc. A list of names can be treated as a table of strings and a two-dimensional character array can be used to store the entire list. For example, a character array **student[30][15]** may be used to store a list of 30 names, each of length not more than 15 characters. Shown below is a table of five cities:

C	h	a	n	d	i	g	a	r	h
M	a	d	r	a	s				
A	h	m	e	d	a	b	a	d	
H	y	d	e	r	a	b	a	d	
B	o	m	b	a	y				

This table can be conveniently stored in a character array city by using the following declaration:

```
char city[ ] [ ]
        {
          "Chandigarh",
          "Madras",
          "Ahmedabad",
          "Hyderabad",
          "Bombay"
        } ;
```

To access the name of the ith city in the list, we write

```
city[i-1]
```

and therefore **city[0]** denotes "Chandigarh", **city[1]** denotes "Madras" and so on. This shows that once an array is declared as two-dimensional, it can be used like a one-dimensional array in further manipulations. That is, the table can be treated as a column of strings.

EXAMPLE 10.9 Write a program that would sort a list of names in alphabetical order.

A program to sort the list of strings in alphabetical order is given in Fig. 10.10. It employs the method of bubble sorting described in Case Study 1 in the previous chapter.

Program

```
#define ITEMS 5
#define MAXCHAR 20
main( )
{
   char string[ITEMS][MAXCHAR], dummy[MAXCHAR];
   int i = 0, j = 0;
   /* Reading the list */
   printf ("Enter names of %d items \n ",ITEMS);
   while (i < ITEMS)
      scanf ("%s", string[i++]);
/* Sorting begins */
   for (i=1; i < ITEMS; i++) /* Outer loop begins */
   {
      for (j=1; j <= ITEMS-i ; j++) /*Inner loop begins*/
      {
         if (strcmp (string[j-1], string[j]) > 0)
         {  /* Exchange of contents */
            strcpy (dummy, string[j-1]);
            strcpy (string[j-1], string[j]);
            strcpy (string[j], dummy );
         }
      } /* Inner loop ends */
} /* Outer loop ends */
/* Sorting completed */
printf ("\nAlphabetical list \n\n");
for (i=0; i < ITEMS ; i++)
   printf ("%s", string[i]);
}
```

Output

```
Enter names of 5 items
London Manchester Delhi Paris Moscow
Alphabetical list
Delhi
London
Manchester
Moscow
Paris
```

Fig. 10.10 *Sorting of strings in alphabetical order*

Note that a two-dimensional array is used to store the list of strings. Each string is read using a **scanf** function with **%s** format. Remember, if any string contains a white space, then the part of the string after the white space will be treated as another item in the list by the **scanf.** In such cases, we should read the entire line as a string using a suitable algorithm. For example, we can use **gets** function to read a line of text containing a series of words. We may also use **puts** function in place of **scanf** for output.

10.10 OTHER FEATURES OF STRINGS

Other aspects of strings we have not discussed in this chapter include:

- Manipulating strings using pointers.
- Using string as function parameters.
- Declaring and defining strings as members of structures.

These topics will be dealt with later when we discuss functions, structures and pointers.