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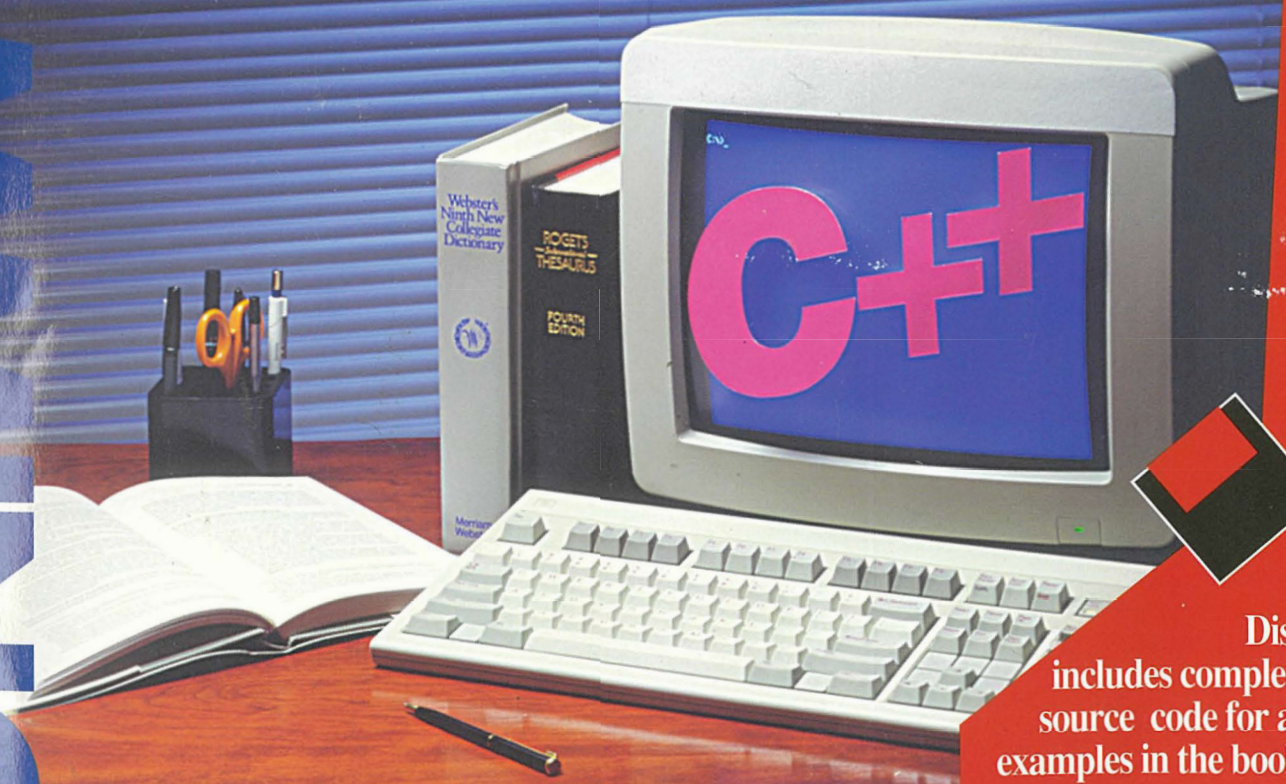

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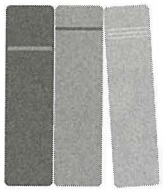

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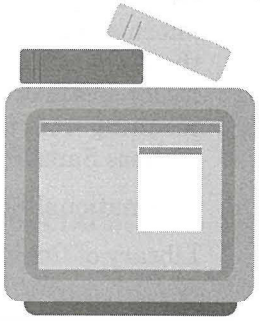

Greg Perry

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This book is for Dr. Roger Wainwright, my first and only "real" computer teacher.

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Review Questions

1. Where did the bubble sort get its name?
2. Are the following values sorted in ascending or descending order?

   33 55 78 78 90 102 435 859 976 4092

3. How does C++ interpret the name of an array?
4. Consider the following array definition:

```
char teams[] = {'E','a','g','l','e','s','\0','R',
                'a','m','s','\0'};
```

   What is printed with each of these statements? (Answer "invalid" if the `cout` is illegal.)

   (a) `cout << teams;`
   (b) `cout << teams + 7;`
   (c) `cout << (teams + 3);`
   (d) `cout << teams[0];`
   (e) `cout << (teams + 0)[0];`
   (f) `cout << (teams + 5);`

Review Exercises

1. Write a program to store six of your friends' ages in a single array. Assign the ages in random order. Print the ages, from low to high, on-screen.
2. Modify the program in Exercise 1 to print the ages in descending order.
3. Using the new approach of subscripting arrays, rewrite the programs in Exercises 1 and 2. Always put a 0 in the subscript brackets, modifying the address instead (use `(ages + 3)[0]` rather than `ages[3]`).

Lesson

Multi-Dimensional Arrays

To explain how to access and manipulate C++ arrays of more than one dimension.

This lesson teaches you how to store tables of data in your C++ program. Some data fits in lists, such as the data discussed in the preceding two lessons, and other data is better suited for tables of information. This lesson takes arrays one step further. The previous lessons introduced single-dimensional arrays—arrays that have only one subscript and represent lists of values.

This lesson introduces arrays of more than one dimension, called *multidimensional arrays.* Multidimensional arrays, sometimes called *tables* or *matrices,* have at least two dimensions (rows and columns). Often they have more than two. If you understand single-dimensional arrays, you should have no trouble understanding arrays that have more than one dimension.

Multidimensional Array Basics

A multidimensional array has more than one subscript. Whereas a single-dimensional array is a list of values, a multidimensional array simulates a table of values, or multiple tables of values. The most commonly used table is a two-dimensional table (an array with two subscripts).

C++ does not store multidimensional arrays in the same way as other programming languages. In C++, a multidimensional array is nothing more than an *array of arrays*. Most of the time, however, you can treat a C++ multidimensional array as you would multidimensional arrays in other programming languages.

Suppose that a football team wanted to track its players' total yardage. The team has eight games scheduled, and there are six rushing players on the team. Table 27.1 shows the team's yardage record.

Table 27.1. A football team's yardage record.

Player Name	*Game 1*	*Game 2*	*Game 3*	*Game 4*	*Game 5*	*Game 6*	*Game 7*	*Game 8*
Downing	1	0	2	1	0	0	0	0
Edwards	0	3	6	4	6	4	5	3
Franks	2	2	3	2	1	0	2	3
Grady	1	3	2	0	1	5	2	1
Howard	3	1	1	1	2	0	1	0
Williams	2	3	1	0	1	2	1	2

Do you see that the football table is a two-dimensional table? It has rows (the first dimension) and columns (the second dimension). Therefore, this is a two-dimensional table with six rows and eight columns. (Generally, the number of rows is specified first.)

Each row has a player's name, and each column has a game number, but these are not part of the actual data. The data consists of only 48 values (six rows by eight columns). The data in a two-dimensional table always is the same type of data; in this case, every value is an integer. If it were a table of salaries, every element would be a floating-point or a double floating-point number.

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How many elements would a 10-by-15 multidimensional table have?

The number of dimensions, in this case two, corresponds to the dimensions in the physical world. The single-dimensional array is a line, or list of values. Two dimensions represent both length and width. You write on a piece of paper in two dimensions; two dimensions represent a flat surface. Three dimensions represent width, length, and depth. You have seen 3-D movies. Not only do the images have width and height, but they also seem to have depth. Figure 27.1 shows what a three-dimensional array looks like if it has a depth of four, six rows, and three columns. Notice that a three-dimensional table resembles a cube.

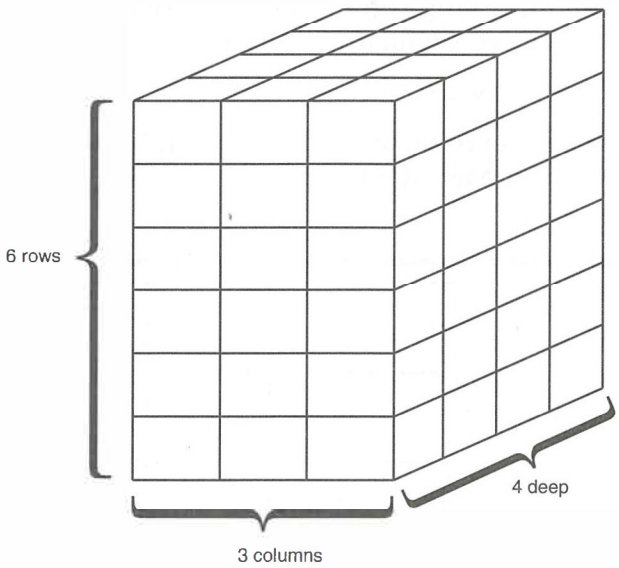

Figure 27.1. A representation of a three-dimensional table (a cube).

It is difficult to visualize more than three dimensions. However, you can think of each dimension after three as another occurrence. In other words, a list of one player's season yardage record can be stored in an array. The team's yardage record is two-dimensional (as shown in Table 27.1). The league, made of up several teams' yardage records, would represent a three-dimensional table. Each team (the depth of the table) has rows and columns of yardage data. Each additional league becomes an additional dimension (another set of data).

C++ enables you to store several dimensions, although "real-world" data rarely requires more than two or three.

Reserving Multidimensional Arrays

When you define storage for a multidimensional array, you must inform C++ that the array has more than one dimension by putting more than one subscript in brackets after the array name. You must include a separate number in brackets for each dimension in the table. For example, to reserve the team data from Table 27.1, you use the following multidimensional array declaration:

```
int teams[8][6];   // Reserves a two-dimensional table
```

Notice that C++ requires you to enclose each dimension in brackets. Most other programming languages do not require two sets of brackets. Do not reserve multidimensional array storage like this:

```
int teams[8,6];   // Invalid table declaration
```

Properly reserving the `teams` table produces a table with 48 elements. Figure 27.2 shows what each element's subscript looks like.

Figure 27.2. Subscripts for the football team table.

columns

[0] [0]	[0] [1]	[0] [2]	[0] [3]	[0] [4]	[0] [5]
[1] [0]	[1] [1]	[1] [2]	[1] [3]	[1] [4]	[1] [5]
[2] [0]	[2] [1]	[2] [2]	[2] [3]	[2] [4]	[2] [5]
[3] [0]	[3] [1]	[3] [2]	[3] [3]	[3] [4]	[3] [5]
[4] [0]	[4] [1]	[4] [2]	[4] [3]	[4] [4]	[4] [5]
[5] [0]	[5] [1]	[5] [2]	[5] [3]	[5] [4]	[5] [5]
[6] [0]	[6] [1]	[6] [2]	[6] [3]	[6] [4]	[6] [5]
[7] [0]	[7] [1]	[7] [2]	[7] [3]	[7] [4]	[7] [5]

rows

If you had to track three teams, each with 15 players and 10 games, the three-dimensional table would be created as follows:

```
int teams[3][15][10]; // Reserves a three-dimensional
                      // table
```

When creating a two-dimensional table, always put the maximum number of rows first and the maximum number of columns second. C++ always uses 0 as the starting subscript of each dimension. The last element, the lower-right element of the `teams` table, is `teams[7][5]`.

A programmer wants to print the first and last values of a four-dimensional table named `MyData` that she defined with this statement:

```
double MyData[2][10][3][60];    // Defines the table
```

After filling the table with values, she writes the following `cout` statements, but they do not produce the first or the last values in the table as she wants to do. What is she doing wrong?

```
cout << MyData[1][1][1][1] << "\n";  // Prints the first value
cout << MyData[2][10][3][60] << "\n";  // Prints the last value
```

How would you define an array named `utilities` that holds five years' worth of monthly utility bill payments from your four utility companies?

Mapping Arrays to Memory

C++ approaches multidimensional arrays a little differently than most programming languages do. When you use subscripts, you do not have to understand the internal representation of multidimensional arrays. However, most C++ programmers think that a deeper understanding of these arrays is important, especially when programming advanced applications.

Remember, a two-dimensional array is actually an *array of arrays*. You program multidimensional arrays as though they were tables with

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rows and columns. A two-dimensional array is actually a single-dimensional array, but each of its elements is not an integer, floating-point, or character, but another array.

Knowing that a multidimensional array is an array of other arrays is critical when passing and receiving such arrays. C++ passes all arrays, including multidimensional arrays, by address. Suppose that you were using an integer array called `scores`, reserved as a 5-by-6 table. You could pass `scores` to a function called `print_it()`, as follows:

```
print_it(scores);   // Passes table to a function
```

The function `print_it()` must identify the type of parameter being passed to it. The `print_it()` function also must recognize that the parameter is an array. If `scores` were single-dimensional, you could receive it as

```
print_it(int scores[])   // Works only if scores
                         // is single-dimensional
```

or

```
print_it(int scores[10])   // Assuming that scores
                           // has 10 elements
```

If `scores` were a multidimensional table, you would have to designate each pair of brackets and put the maximum number of subscripts in its brackets, as in

```
print_it(int scores[5][6])   // Informs print_it() of
                             // the array's dimensions
```

or

```
print_it(int scores[][6])   // Informs print_it() of
                            // the array's dimensions
```

Notice that you do not have to explicitly state the maximum subscript on the first dimension when receiving multidimensional arrays, but you must designate the second. If `scores` were a three-dimensional table, dimensioned as 10-by-5-by-6, you would receive it with `print_it()` as

```
print_it(int scores[][5][6])   // Only first dimension
                               // is optional
```

or

```
print_it(int scores[10][5][6])   // Inform print_it() of
                                 // array's dimensions
```

Write a statement that passes a four-dimensional table named `Bills`, defined with this statement:

```
double Bills[3][5][2][7];
```

to a function named `PayThem()`.

Write the first line of `Bills` that receives the `Bills` table.

Initializing Multidimensional Arrays

C++ enables you to initialize a multidimensional array when you define it. As with single-dimensional arrays, you initialize multidimensional arrays with braces that designate dimensions. Because a multidimensional array is an array of arrays, you can nest braces when you initialize them.

The following three array definitions fill the three arrays `ara1`, `ara2`, and `ara3`, as shown in Figure 27.3:

```
int ara1[5] = {8, 5, 3, 25, 41};    // Single-dimensional array
int ara2[2][4] = {{4, 3, 2, 1},{1, 2, 3, 4}};
int ara3[3][4] = {{1, 2, 3, 4},{5, 6, 7, 8},{9, 10, 11, 12}};
```

Notice that the multidimensional arrays are stored in row order. In `ara3`, the first row receives the first four elements of the definition (1, 2, 3, and 4).

Fill in the boxes of Figure 27.4 to show how the following statement initializes a table.

```
int Table[4][2] = {2, 1, 5, 4, 6, 7, 4, 2};    // Fill up Table
```

To make a multidimensional array initialization look more like the array's subscripts, some programmers like to show how arrays are filled. Because C++ programs are free-form, you can initialize `ara2` and `ara3` as

```
int ara2[2][4] = {{4, 3, 2, 1},    // Does exactly the same
                  {1, 2, 3, 4}};   // thing as before
```

and

```
int ara3[3][4] = {{1, 2, 3, 4},
                  {5, 6, 7, 8},
                  {9,10, 11, 12};   // Visually more
                                    // obvious
```

Figure 27.3. After initializing a table.

	[0]	[1]	[2]	[3]	[4]
ara 1	8	5	3	25	41

ara 2

4	3	2	1
1	2	3	4

ara 3

1	2	3	4
5	6	7	8
9	10	11	12

Figure 27.4. Fill in the values for the `Table` *elements.*

Table

You can initialize a multidimensional array as if it were single-dimensional in C++. You must keep track of the row order if you do this. For instance, the following two definitions also reserve storage for and initialize `ara2` and `ara3`:

```
int ara2[2][4] = {4, 3, 2, 1, 1, 2, 3, 4};
int ara3[3][4] = {1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13};
```

There is no difference between initializing `ara2` and `ara3` with or without the nested braces. The nested braces seem to show the dimensions and how C++ fills them a little better, but the choice of using nested braces is yours.

Rewrite the following array definition to show its two dimensions in the list of values that initialize it. (Break the list of values into a row-and-column appearance using more braces.)

```
char Initials[3][3] = {9,8,7,6,5,4,3,2,1};
```

TIP: Multidimensional arrays (unless they are global) are not initialized to specific values unless you assign them values at declaration time or in the program. As with single-dimensional arrays, if you initialize one or more of the elements, but not all of them, C++ fills the rest with zeros. If you want to fill an entire multidimensional array with zeros, you can do so with the following:

```
float sales[3][4][7][2] = {0};    // Fills all sales
                                  // with zeros
```

Tables and `for` Loops

As the following examples show, nested `for` loops are useful when you want to loop through every element of a multidimensional table.

For instance, this section of code

```
for (row = 0; row < 2; row++)
   { for (col = 0; col < 3; col++)
```


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```
        { cout << row << " " << col "\n"; }
    }
```

produces the following output:

```
0    0
0    1
0    2
1    0
1    1
1    2
```

These numbers are the subscripts, in row order, for a two-row by three-column table dimensioned with

```
int table[2][3];
```

Notice that there are as many `for` loops as there are subscripts in the array (two). The outside loop represents the first subscript (the rows), and the inside loop represents the second subscript (the columns). The nested `for` loop steps through each element of the table.

You can use `cin`, `gets()`, `get`, and other input functions to fill a table, and you also can assign values to the elements when declaring the table. More often, the data comes from data files on the disk. Regardless of what method is used to store the values in multidimensional arrays, nested `for` loops are excellent control statements to step through the subscripts.

Suppose that you used the following statement to reserve enough memory elements for a television station's ratings (A through D) for one week:

```
char ratings[7][48];
```

These statements reserve enough elements to hold seven days (the rows) of ratings for each 30-minute time slot (48 of them in a day). Every element in a table is always the same type. In this case, each element is a character variable. Some are initialized with the following assignment statements:

```
shows[3][12] = 'B';    // Stores B in 4th row, 13th column
shows[1][5] = 'A' ;    // Stores C in 2nd row, 6th column
shows[6][20] = getch();    // Stores the letter that the
                           // user types
```

The following complete program defines, initializes, and prints the values from a two-dimensional table. Suppose that a video store sells two grades of video tapes, High Grade and Regular. Each grade of tape comes in one of four lengths: 2-hour, 4-hour, 6-hour, or 8-hour. The tape inventory is well-suited for a two-dimensional table. The store determined that the tapes should have the following retail prices:

	2-Hour	*4-Hour*	*6-Hour*	*8-Hour*
High Grade	2.39	2.85	3.29	3.99
Regular	1.75	2.19	2.69	2.95

The store wants to store the price of each tape in a table for easy access. Typically, you use a nested `for` loop to print rows and columns.

To add the titles, simply print a row of titles before the first row of values, then print a new column title before each column. The following program stores the tape table, initializes it, and prints the output to the screen.

```
// Filename: TAPE.CPP
// Initializes and prints tape prices
// in a table format with titles
#include <iostream.h>
#include <iomanip.h>
void main()
{
   float tapes[2][4];   // Table of tape prices
   int row, col;

   tapes[0][0] = 2.39;   // Row 1, column 1
   tapes[0][1] = 2.85;   // Row 1, column 2
   tapes[0][2] = 3.29;   // Row 1, column 3
   tapes[0][3] = 3.99;   // Row 1, column 4
   tapes[1][0] = 1.75;   // Row 2, column 1
   tapes[1][1] = 2.19;   // Row 2, column 2
   tapes[1][2] = 2.69;   // Row 2, column 3
   tapes[1][3] = 2.95;   // Row 2, column 4

   // Prints the column titles
   cout << "\t\t2-Hour\t\t4-Hour\t\t6-Hour\t\t8-Hour\n";

   // Prints the prices
   for (row = 0; row < 2; row++)
```

```
        { if (row == 0)
         { cout << "High Grade\t"; }
          else
            { cout << "Regular\t\t"; }
          for (col=0; col<4; col++)   // Prints the current row
              { cout << setprecision(2) << "$" << tapes[row][col]
                     << "\t\t";
             }
    }

    return;
}
```

Here is the program's output:

```
              2-Hour      4-Hour      6-Hour      8-Hour
High Grade    $2.39       $2.85       $3.29       $3.99
Regular       $1.75       $2.19       $2.69       $2.95
```

Review Questions

1. What statement reserves a two-dimensional table of integers called `scores` with five rows and six columns?
2. What statement reserves a three-dimensional table of four character arrays called `initials` with 10 rows and 20 columns?
3. In the following statement, which subscript (first or second) represents rows and which represents columns?

   ```
   int weights[5][10];
   ```

4. How many elements are reserved with the following statement?

   ```
   int ara[5][6];
   ```

5. The following table of integers is called `ara`:

4	1	3	5	9
10	2	12	1	6
25	42	2	91	8

What values do the following elements contain?

(a) `ara[2][2]`

(b) `ara[0][1]`

(c) `ara[2][3]`

(d) `ara[2][4]`

6. What control statement is best for stepping through multidimensional arrays?

7. Notice the following section of a program:

```
int grades[3][5] = {80,90,96,73,65,67,90,68,92,84,70,
                    55,95,78,100};
```

What are the values of the following?

(a) `grades[2][3]`

(b) `grades[2][4]`

(c) `grades[0][1]`

Review Exercises

1. Write a program that stores and prints the numbers from 1 to 21 in a 3-by-7 table. (*Hint:* Remember that C++ begins subscripts at 0.)

2. Write a program that reserves storage for three years' worth of sales data for five salespeople. Use assignment statements to fill the table with data, then print it, one value per line.

3. Instead of using assignment statements, use the `cin` function to fill the salespeople data from Exercise 2.

4. Write a program that tracks the grades for five classes, each having 10 students. Input the data using the `cin` function. Print the table in its native row-and-column format.

5. Rewrite the TAPE.CPP program presented in this lesson so that it prints a title at the top of the table that says "Tape Inventory," and add a third row to the table for a new Medium grade of tape.

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