Chapter 7

Arrays

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Overview

7.1 Introduction to Arrays

7.2 Arrays in Functions

7.3 Programming with Arrays

7.4 Multidimensional Arrays

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7.1

Introduction to Arrays

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Introduction to Arrays

- An array is used to process a collection of data of the same type
  - Examples: A list of names
    A list of temperatures
- Why do we need arrays?
  - Imagine keeping track of 5 test scores, or 100, or 1000 in memory
    - How would you name all the variables?
    - How would you process each of the variables?

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Declaring an Array

- An array, named score, containing five variables of type int can be declared as
  int score[5];
- This is like declaring 5 variables of type int:
  score[0], score[1], … , score[4]
- The value in brackets is called
  - A subscript
  - An index

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The Array Variables

- The variables making up the array are referred to as
  - Indexed variables
  - Subscripted variables
  - Elements of the array
- The number of indexed variables in an array is the declared size, or size, of the array
  - The largest index is one less than the size
  - The first index value is zero

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Array Variable Types

- An array can have indexed variables of any type

- All indexed variables in an array are of the same type
  - This is the base type of the array

- An indexed variable can be used anywhere an ordinary variable of the base type is used

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Using [ ] With Arrays

- In an array declaration, [ ]'s enclose the size of the array such as this array of 5 integers:

  int score [5];

- When referring to one of the indexed variables, the [ ]'s enclose a number identifying one of the indexed variables
  - score[3] is one of the indexed variables
  - The value in the [ ]'s can be any expression that evaluates to one of the integers
    0 to (size -1)

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Indexed Variable Assignment

- To assign a value to an indexed variable, use the assignment operator:

```
int n = 2;
score[n + 1] = 99;
```

  - In this example, variable score[3] is assigned 99

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Loops And Arrays

- for-loops are commonly used to step through arrays

  First index is 0

  Last index is (size – 1)

  - Example:

    ```
    for (i = 0; i < 5; i++)
    {
          cout << score[i] << " off by "
           << (max – score[i]) << endl;
    }
    ```

    could display the difference between each score and the maximum score stored in an array

Display 7.1

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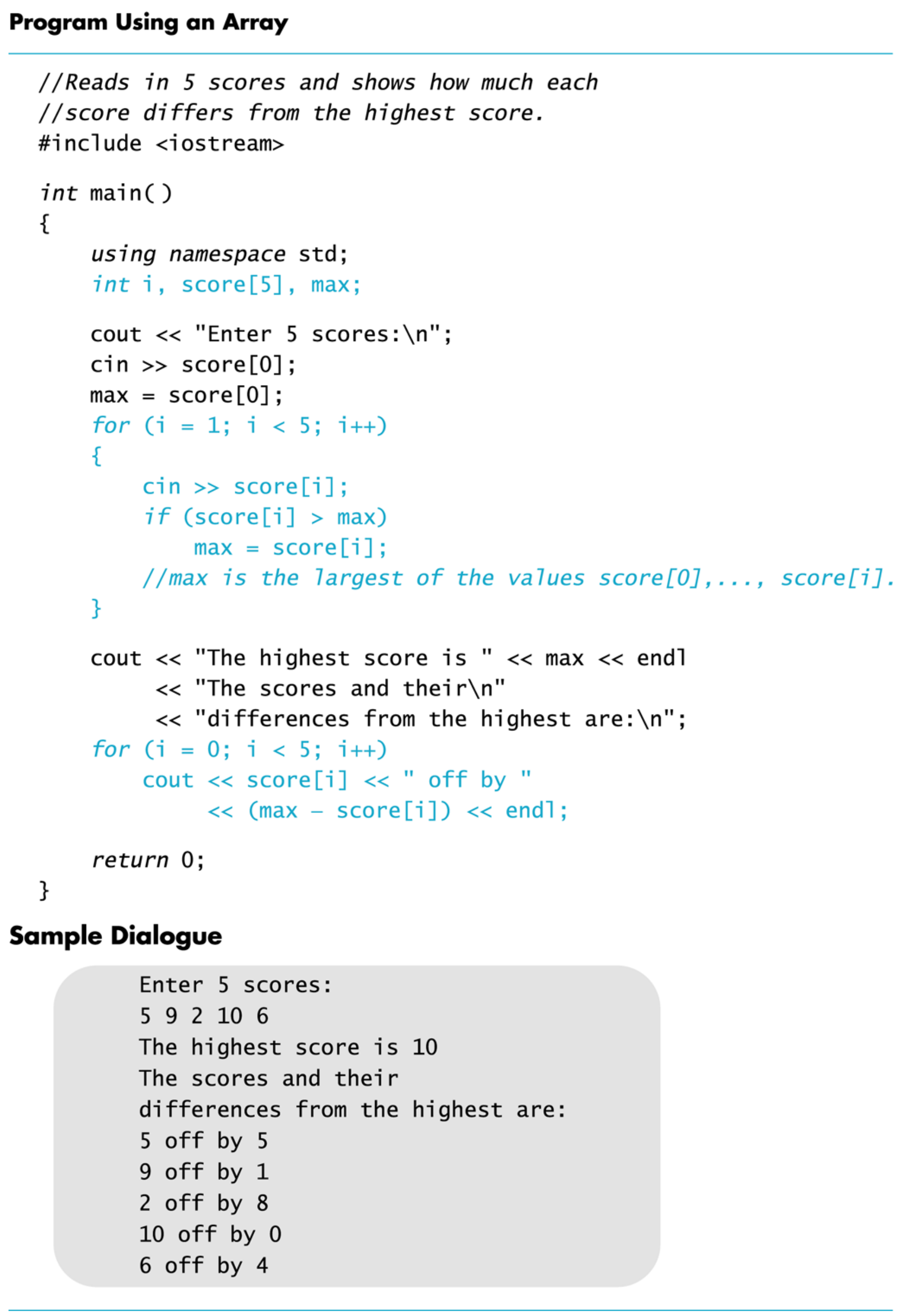
Display 7.1



Program Using an Array

```
//Reads in 5 scores and shows how much each
//score differs from the highest score.
#include <iostream>

int main( )
{
    using namespace std;
    int i, score[5], max;

    cout << "Enter 5 scores:\n";
    cin >> score[0];
    max = score[0];
    for (i = 1; i < 5; i++)
    {
        cin >> score[i];
        if (score[i] > max)
            max = score[i];
        //max is the largest of the values score[0],..., score[i].
    }

    cout << "The highest score is " << max << endl
         << "The scores and their\n"
         << "differences from the highest are:\n";
    for (i = 0; i < 5; i++)
        cout << score[i] << " off by "
             << (max - score[i]) << endl;

    return 0;
}
```

Sample Dialogue

```
Enter 5 scores:
5 9 2 10 6
The highest score is 10
The scores and their
differences from the highest are:
5 off by 5
9 off by 1
2 off by 8
10 off by 0
6 off by 4
```

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Constants and Arrays

- Use constants to declare the size of an array
  - Using a constant allows your code to be easily altered for use on a smaller or larger set of data
    - Example:

      ```
      const int  NUMBER_OF_STUDENTS = 50;
      int score[NUMBER_OF_STUDENTS];
      …
      for ( i = 0; i < NUMBER_OF_STUDENTS;
                i++)
      cout << score[i] << " off by "
             << (max – score[i]) << endl;
      ```

    - Only the value of the constant must be changed to make this code work for any number of students

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Variables and Declarations

- Most compilers do not allow the use of a variable to declare the size of an array

  Example:
  ```
  cout << "Enter number of students: ";
  cin >> number;
  int score[number];
  ```

- This code is illegal on many compilers
- Later we will see dynamic arrays which supports this idea

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Array Declaration Syntax

- To declare an array, use the syntax:
  Type_Name   Array_Name[Declared_Size];
  - Type_Name can be any type
  - Declared_Size can be a constant to make your program more versatile
- Once declared, the array consists of the indexed variables:
  Array_Name[0] to Array_Name[Declared_Size -1]

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Computer Memory

- Computer memory consists of numbered locations called bytes
  - A byte's number is its address
- A simple variable is stored in consecutive bytes
  - The number of bytes depends on the variable's type
- A variable's address is the address of its first byte

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Arrays and Memory

- Declaring the array   int a[6]
  - Reserves memory for six variables of type int
  - The variables are stored one after another
  - The address of a[0] is remembered
    - The addresses of the other indexed variables is not remembered
  - To determine the address of a[3]
    - Start at a[0]
    - Count past enough memory for three integers to find a[3]

Display 7.2

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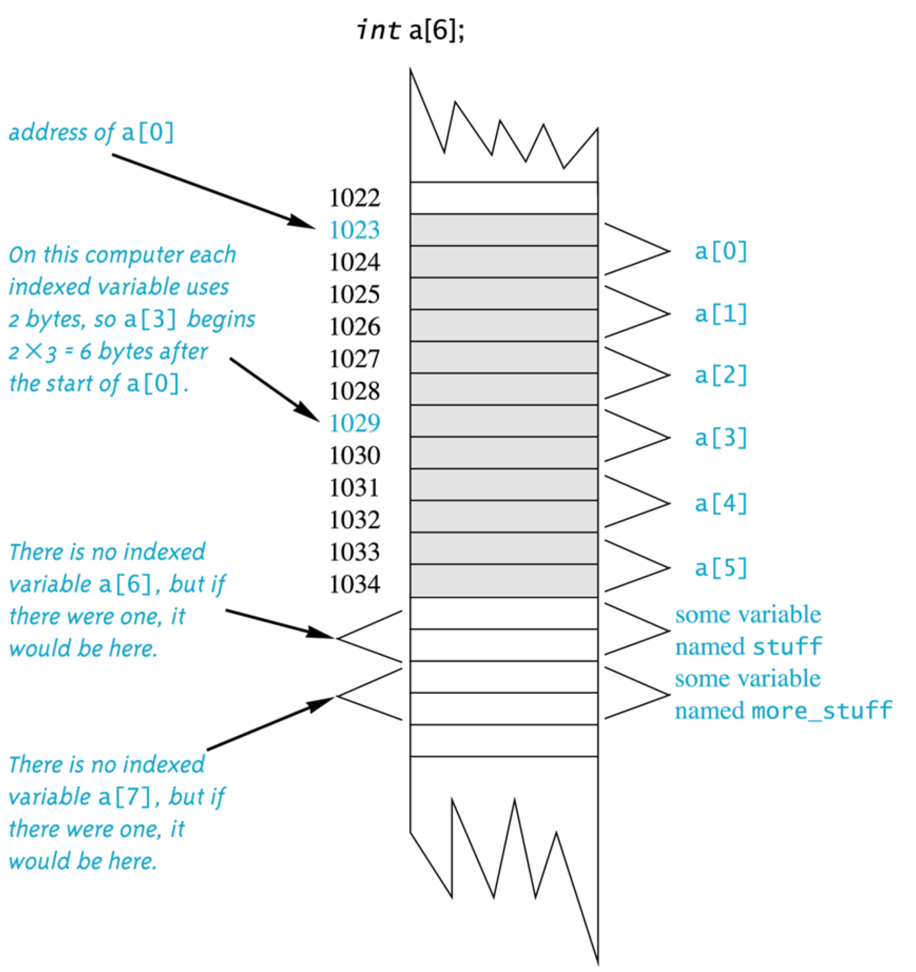
Display 7.2

An Array in Memory


int a[6];
address of a[0]
On this computer each indexed variable uses 2 bytes, so a[3] begins 2×3 = 6 bytes after the start of a[0].
There is no indexed variable a[6], but if there were one, it would be here.
There is no indexed variable a[7], but if there were one, it would be here.
1022
1023
1024
1025
1026
1027
1028
1029
1030
1031
1032
1033
1034
a[0]
a[1]
a[2]
a[3]
a[4]
a[5]
some variable named stuff
some variable named more_stuff

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Array Index Out of Range

- A common error is using a nonexistent index
  - Index values for int a[6] are the values 0 through 5
  - An index value not allowed by the array declaration is out of range
  - Using an out of range index value doe not produce an error message!

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Out of Range Problems

- If an array is declared as: int a[6];
  and an integer is declared as: int i = 7;
- Executing the statement a[i] = 238; causes…
  - The computer to calculate the address of the illegal a[7]
  - (This address could be where some other variable is stored)
  - The value 238 is stored at the address calculated for a[7]
  - No warning is given!

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Initializing Arrays

- To initialize an array when it is declared
  - The values for the indexed variables are enclosed in braces and separated by commas
- Example: int children[3] = { 2, 12, 1 };
  Is equivalent to:

```
int children[3];
children[0] = 2;
children[1] = 12;
children[2] = 1;
```

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Default Values

- If too few values are listed in an initialization statement
  - The listed values are used to initialize the first of the indexed variables
  - The remaining indexed variables are initialized to a zero of the base type
  - Example: int a[10] = {5, 5};
    initializes a[0] and a[1] to 5 and
    a[2] through a[9] to 0

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Un-initialized Arrays

- If no values are listed in the array declaration, some compilers will initialize each variable to a zero of the base type
  - DO NOT DEPEND ON THIS!

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Range-Based For Loops

- C++11 includes a new type of for loop, the range-based for loop, that simplifies iteration over every element in an array. The syntax is shown below:

```
for (datatype varname : array)
{
        // varname is successively set to each
        // element in the array
}
```

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Range-Based For Loop Example

- The following code outputs 2 4 6 8

```
int arr[ ] = {2, 4, 6, 8};
for (int x : arr)
        cout << x;
cout << endl;
```

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Section 7.1 Conclusion

- Can you
  - Describe the difference between a[4] and int a[5]?
  - Show the output of

```
char symbol[3] = {'a', 'b', 'c'};
for (int index = 0; index < 3; index++)
   cout << symbol[index];
```

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7.2

Arrays in Functions

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Arrays in Functions

- Indexed variables can be arguments to functions
  - Example: If a program contains these declarations:

```
int i, n, a[10];
void my_function(int n);
```

  - Variables a[0] through a[9] are of type int, making these calls legal:

```
my_function( a[ 0 ] );
my_function( a[ 3 ] );
my_function( a[  i ]  );
```

Display 7.3

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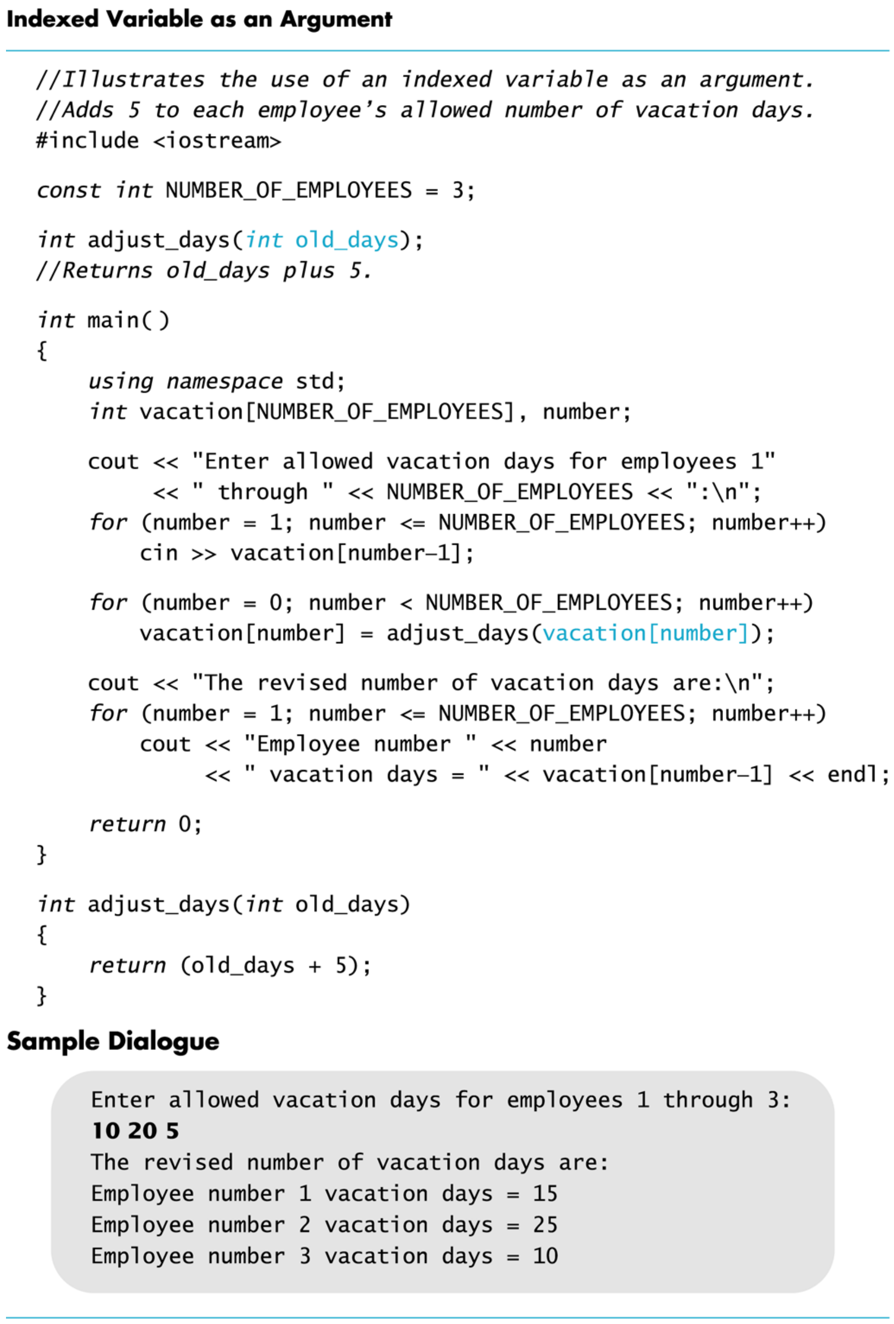
Display 7.3



Indexed Variable as an Argument

```
//Illustrates the use of an indexed variable as an argument.
//Adds 5 to each employee's allowed number of vacation days.
#include <iostream>

const int NUMBER_OF_EMPLOYEES = 3;

int adjust_days(int old_days);
//Returns old_days plus 5.

int main( )
{
    using namespace std;
    int vacation[NUMBER_OF_EMPLOYEES], number;

    cout << "Enter allowed vacation days for employees 1"
         << " through " << NUMBER_OF_EMPLOYEES << ":\n";
    for (number = 1; number <= NUMBER_OF_EMPLOYEES; number++)
        cin >> vacation[number-1];

    for (number = 0; number < NUMBER_OF_EMPLOYEES; number++)
        vacation[number] = adjust_days(vacation[number]);

    cout << "The revised number of vacation days are:\n";
    for (number = 1; number <= NUMBER_OF_EMPLOYEES; number++)
        cout << "Employee number " << number
             << " vacation days = " << vacation[number-1] << endl;

    return 0;
}

int adjust_days(int old_days)
{
    return (old_days + 5);
}
```

Sample Dialogue

```
Enter allowed vacation days for employees 1 through 3:
10 20 5
The revised number of vacation days are:
Employee number 1 vacation days = 15
Employee number 2 vacation days = 25
Employee number 3 vacation days = 10
```

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Arrays as Function Arguments

- A formal parameter can be for an entire array
  - Such a parameter is called an array parameter
    - It is not a call-by-value parameter
    - It is not a call-by-reference parameter
    - Array parameters behave much like call-by-reference parameters

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Array Parameter Declaration

- An array parameter is indicated using empty brackets in the parameter list such as

```
void fill_up(int a[ ], int size);
```

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Function Calls With Arrays

- If function fill_up is declared in this way:
  ```
  void fill_up(int a[ ], int size);
  ```

- and array score is declared this way:
  ```
  int score[5], number_of_scores;
  ```

- fill_up is called in this way:
  ```
  fill_up(score, number_of_scores);
  ```

Display 7.4

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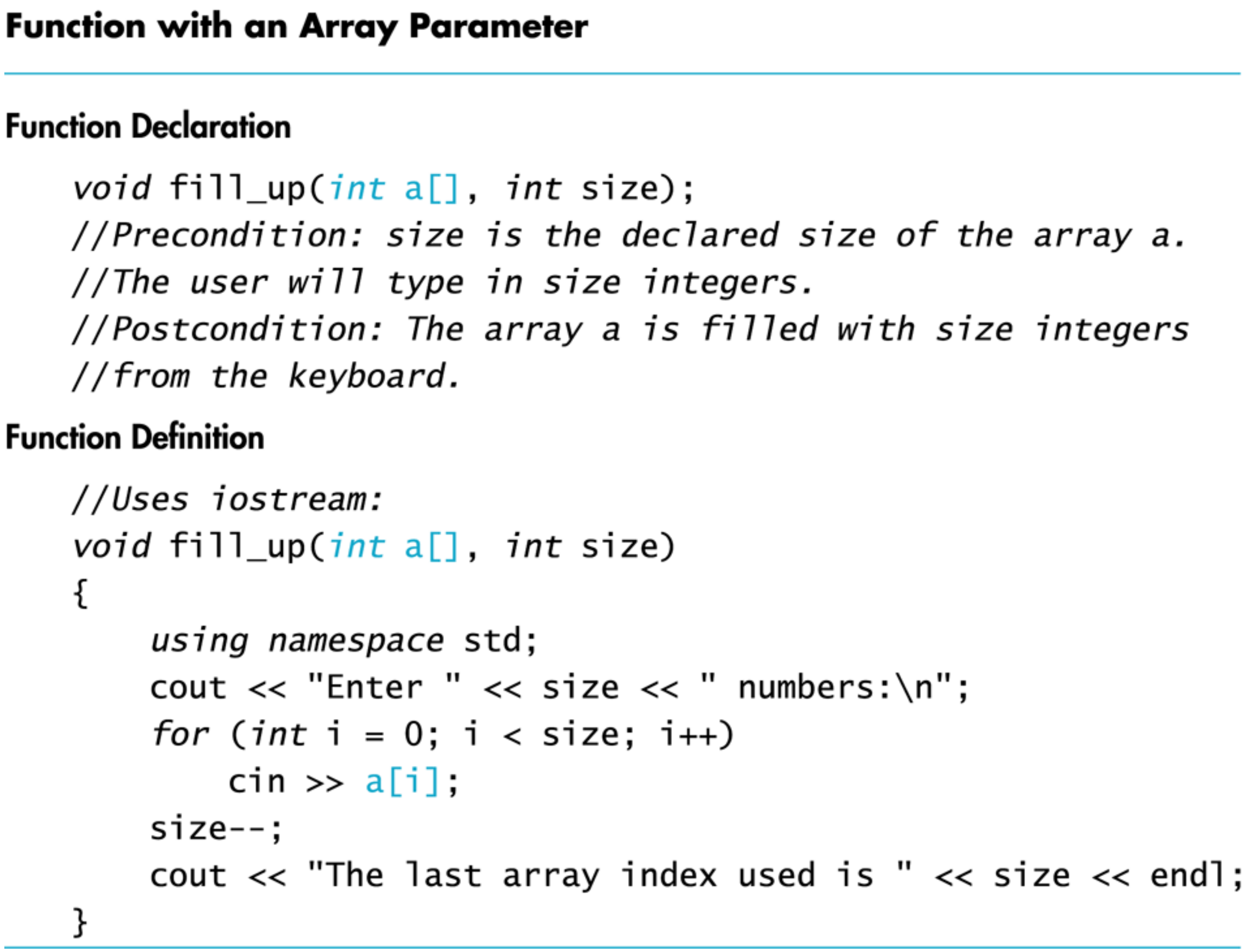
Display 7.4



Function with an Array Parameter

Function Declaration

```
void fill_up(int a[], int size);
//Precondition: size is the declared size of the array a.
//The user will type in size integers.
//Postcondition: The array a is filled with size integers
//from the keyboard.
```

Function Definition

```
//Uses iostream:
void fill_up(int a[], int size)
{
    using namespace std;
    cout << "Enter " << size << " numbers:\n";
    for (int i = 0; i < size; i++)
        cin >> a[i];
    size--;
    cout << "The last array index used is " << size << endl;
}
```

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Function Call Details

- A formal parameter is identified as an array parameter by the [ ]'s with no index expression

```
void fill_up(int a[ ], int size);
```

- An array argument does not use the [ ]'s

```
fill_up(score, number_of_scores);
```

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Array Formal Parameters

- An array formal parameter is a placeholder for the argument
  - When an array is an argument in a function call, an action performed on the array parameter is performed on the array argument

  - The values of the indexed variables can be changed by the function

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Array Argument Details

- What does the computer know about an array?
  - The base type
  - The address of the first indexed variable
  - The number of indexed variables
- What does a function know about an array argument?
  - The base type
  - The address of the first indexed variable

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Array Parameter Considerations

- Because a function does not know the size of an array argument…
  - The programmer should include a formal parameter that specifies the size of the array
  - The function can process arrays of various sizes
    - Function fill_up from Display 7.4 can be used to fill an array of any size:

```
fill_up(score, 5);
fill_up(time, 10);
```

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const Modifier

- Array parameters allow a function to change the values stored in the array argument
- If a function should not change the values of the array argument, use the modifier const
- An array parameter modified with const is a constant array parameter
  - Example:

```
void show_the_world(const int a[ ], int size);
```

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Using const With Arrays

- If const is used to modify an array parameter:
  - const is used in both the function declaration and definition to modify the array parameter
  - The compiler will issue an error if you write code that changes the values stored in the array parameter

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Function Calls and const

- If a function with a constant array parameter calls another function using the const array parameter as an argument…
  - The called function must use a constant array parameter as a placeholder for the array
  - The compiler will issue an error if a function is called that does not have a const array parameter to accept the array argument

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const Parameters Example

-
  ```
  double compute_average(int a[ ], int size);

  void show_difference(const int a[ ], int size)
  {
        double average = compute_average(a, size);
         …
  }
  ```
- compute_average has no constant array parameter
- This code generates an error message because compute_average could change the array parameter

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Returning An Array

- Recall that functions can return a value of type int, double, char, …, or a class type
- Functions cannot return arrays
- We learn later how to return a pointer to an array

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Case Study: Production Graph

- Problem Definition:
  - We are writing a program for the Apex Plastic Spoon Company
  - The program will display a bar graph showing the production of each of four plants for a week
  - Each plant has separate records for each department
  - Input is entered plant by plant
  - Output shows one asterisk for each 1000 units, and production is rounded to the nearest 1,000 units

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Analysis of The Problem

- Use an array named production to hold total production of each plant
  - Production for plant n is stored in production[n-1]

- Program must scale production to nearest 1,000 units to display asterisks in the bar

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Production Graph Sub-Tasks

- Analysis leads to the following sub-tasks
  - input_data: Read input for each plant
    Set production [plant_number -1]
    to the total production for plant
    number n
  - scale: For each plant, change
    production[plant_number]
    to the correct number of asterisks
  - graph: Output the bar graph

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More Analysis Details

- The entire array will be an argument for the functions we write to perform the subtasks
  - We will also include a formal parameter for the size
  - The size of the array is equal to the number of plants
  - We will use a constant for the number of plants

Display 7.5

- The function declarations and main function for the production graph program are found in

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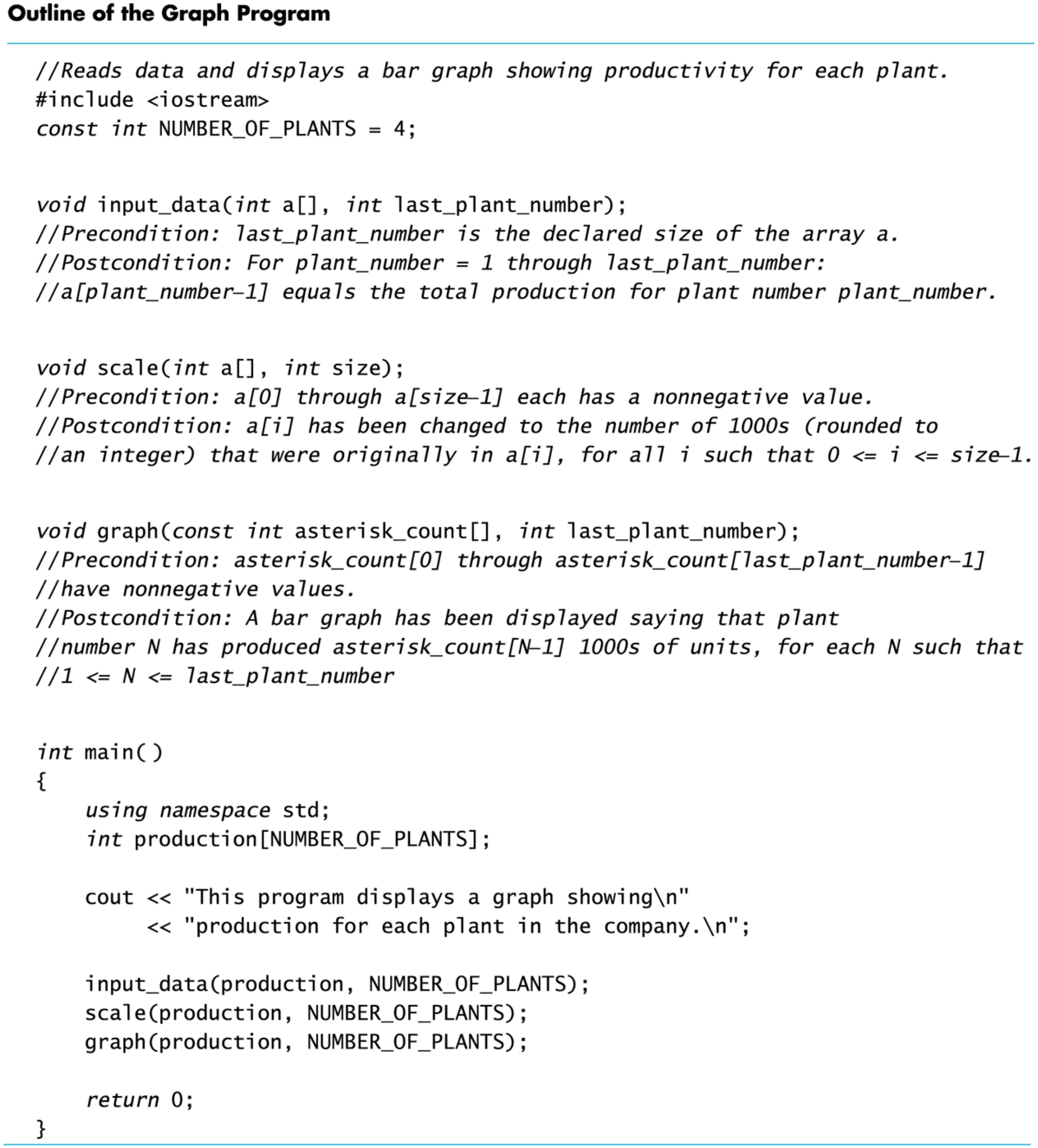
Display 7.5



Outline of the Graph Program

```
//Reads data and displays a bar graph showing productivity for each plant.
#include <iostream>
const int NUMBER_OF_PLANTS = 4;


void input_data(int a[], int last_plant_number);
//Precondition: last_plant_number is the declared size of the array a.
//Postcondition: For plant_number = 1 through last_plant_number:
//a[plant_number-1] equals the total production for plant number plant_number.


void scale(int a[], int size);
//Precondition: a[0] through a[size-1] each has a nonnegative value.
//Postcondition: a[i] has been changed to the number of 1000s (rounded to
//an integer) that were originally in a[i], for all i such that 0 <= i <= size-1.


void graph(const int asterisk_count[], int last_plant_number);
//Precondition: asterisk_count[0] through asterisk_count[last_plant_number-1]
//have nonnegative values.
//Postcondition: A bar graph has been displayed saying that plant
//number N has produced asterisk_count[N-1] 1000s of units, for each N such that
//1 <= N <= last_plant_number


int main( )
{
    using namespace std;
    int production[NUMBER_OF_PLANTS];

    cout << "This program displays a graph showing\n"
         << "production for each plant in the company.\n";

    input_data(production, NUMBER_OF_PLANTS);
    scale(production, NUMBER_OF_PLANTS);
    graph(production, NUMBER_OF_PLANTS);

    return 0;
}
```

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Algorithm Design: input_data

- We must read all departments' data for each plant and add them to produce a plant's total
  - Algorithm for input_data:

```
for plant_number is 1, 2, …, last_plant_number

do the following
        Read all the data for plant number plant_number
        Sum the numbers
        Set production[plant_number – 1] to the total
```

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Coding input_data

- The algorithm can be translated to C++ as:

```
void input_data(int a [ ], int last_plant_number)
{
        using namespace std;

        for (int plant_number = 1;
             plant_number <= last_plant_number;
             plant_number++)
        {
          cout << endl;
            << "Enter production for plant"
            << plant_number << endl;
           get_total( a[plant_number -1] );
        }
}
```

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Testing input_data

- Each function should be tested in a program in which it is the only untested function
- Because input_data calls get_total, get_total is tested first
- Once tested, get_total can be used to test input_data

Display 7.6 (1)

Display 7.6 (2)

Display 7.6 (3)

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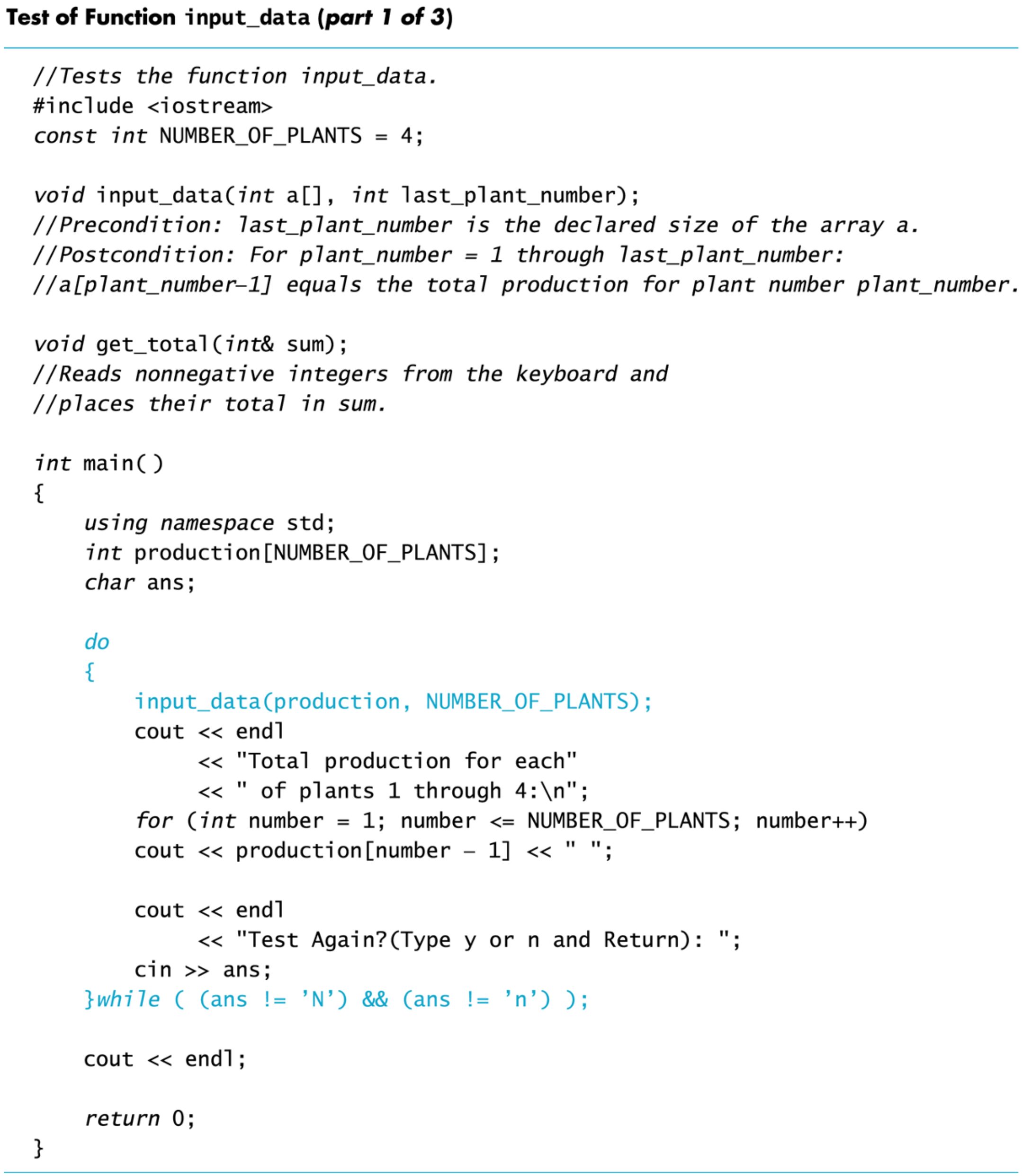
Display 7.6 (1/3)



Test of Function input_data (*part 1 of 3*)

```
//Tests the function input_data.
#include <iostream>
const int NUMBER_OF_PLANTS = 4;

void input_data(int a[], int last_plant_number);
//Precondition: last_plant_number is the declared size of the array a.
//Postcondition: For plant_number = 1 through last_plant_number:
//a[plant_number-1] equals the total production for plant number plant_number.

void get_total(int& sum);
//Reads nonnegative integers from the keyboard and
//places their total in sum.

int main( )
{
    using namespace std;
    int production[NUMBER_OF_PLANTS];
    char ans;

    do
    {
        input_data(production, NUMBER_OF_PLANTS);
        cout << endl
             << "Total production for each"
             << " of plants 1 through 4:\n";
        for (int number = 1; number <= NUMBER_OF_PLANTS; number++)
        cout << production[number - 1] << " ";

        cout << endl
             << "Test Again?(Type y or n and Return): ";
        cin >> ans;
    }while ( (ans != ’N’) && (ans != ’n’) );

    cout << endl;

    return 0;
}
```

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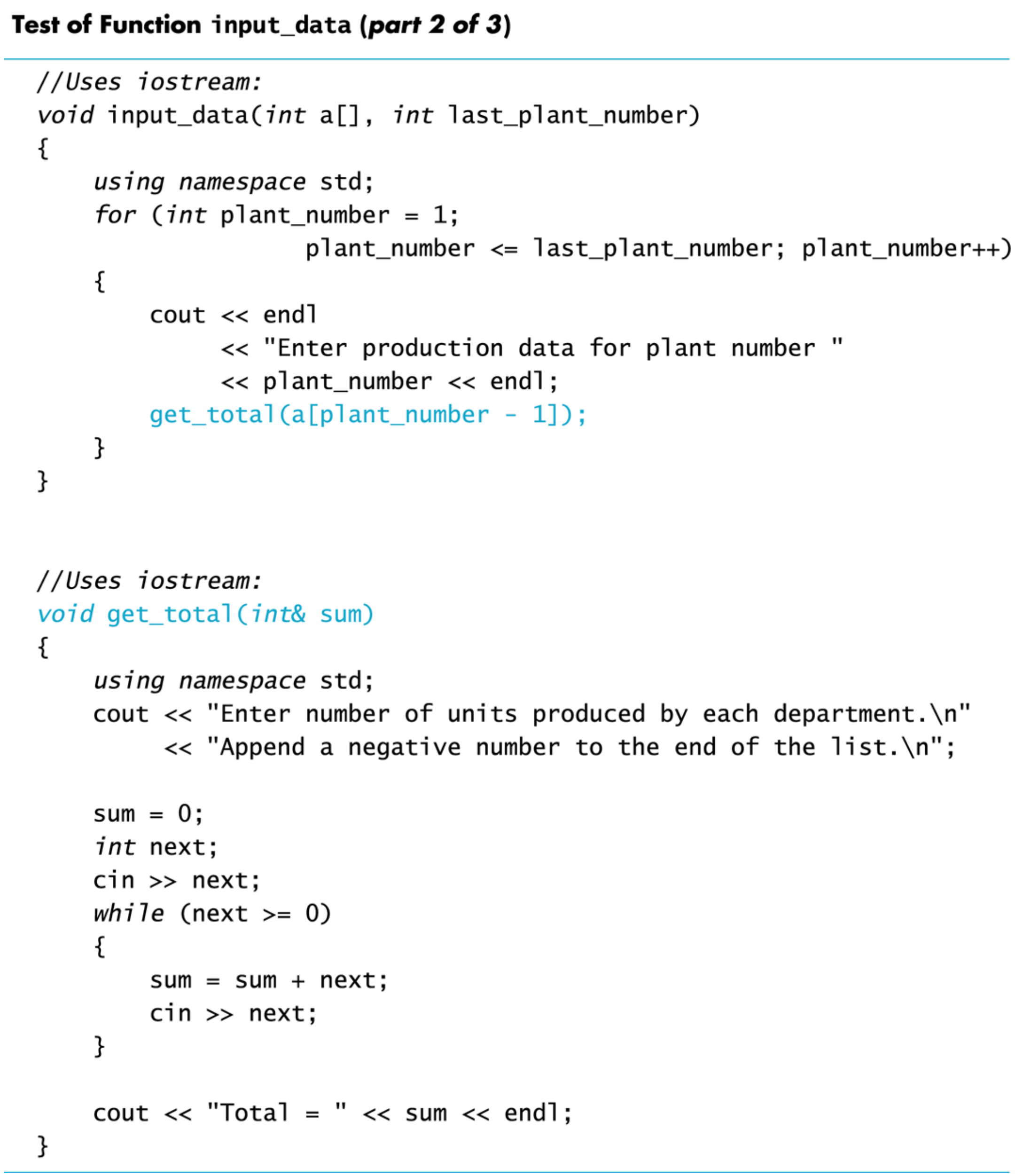
Display 7.6 (2/3)



Test of Function `input_data` (*part 2 of 3*)

```
//Uses iostream:
void input_data(int a[], int last_plant_number)
{
    using namespace std;
    for (int plant_number = 1;
                   plant_number <= last_plant_number; plant_number++)
    {
        cout << endl
             << "Enter production data for plant number "
             << plant_number << endl;
        get_total(a[plant_number - 1]);
    }
}


//Uses iostream:
void get_total(int& sum)
{
    using namespace std;
    cout << "Enter number of units produced by each department.\n"
         << "Append a negative number to the end of the list.\n";

    sum = 0;
    int next;
    cin >> next;
    while (next >= 0)
    {
        sum = sum + next;
        cin >> next;
    }

    cout << "Total = " << sum << endl;
}
```

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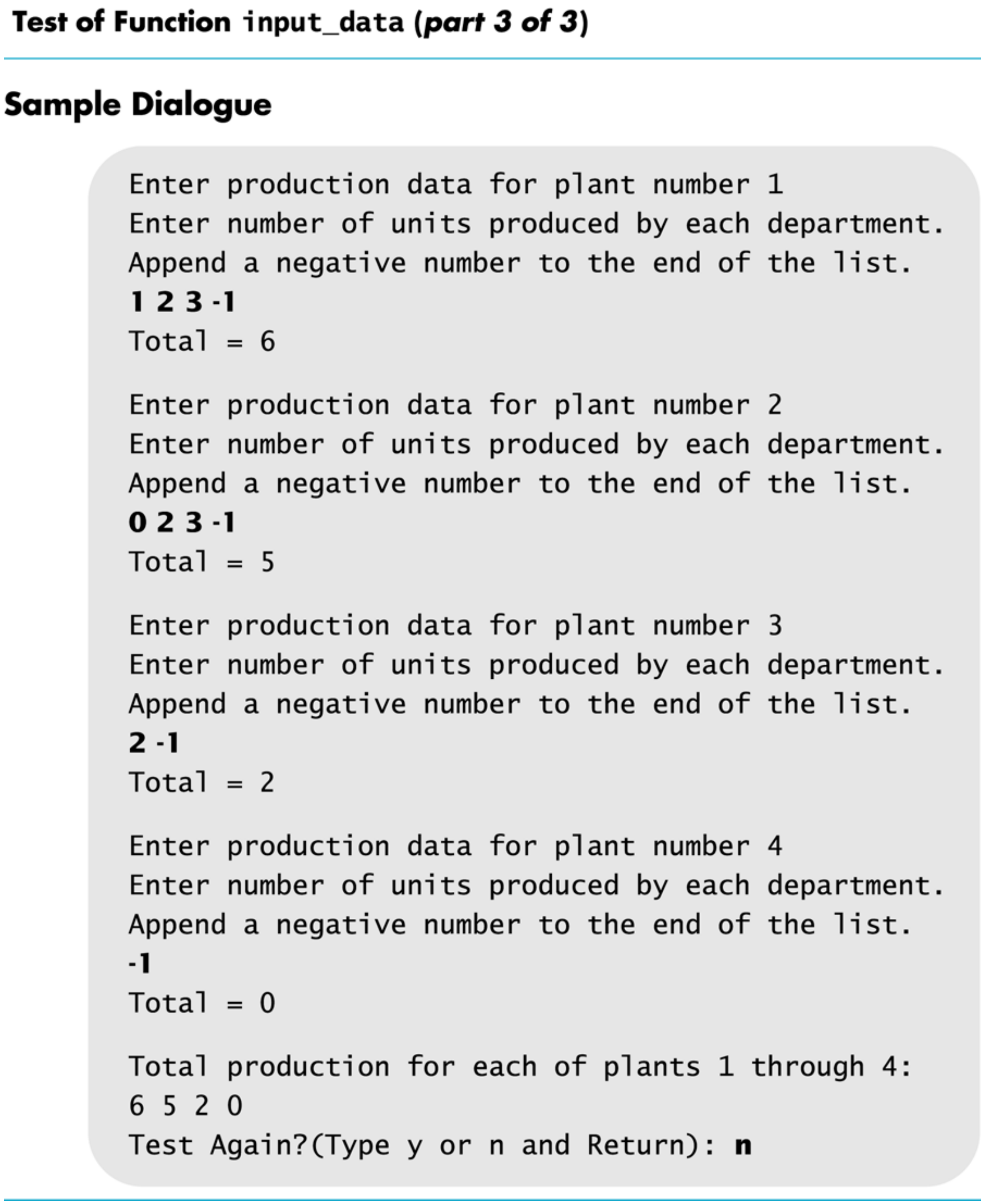
Display 7.6 (3/3)



Test of Function `input_data` **(*part 3 of 3*)**

Sample Dialogue

```
Enter production data for plant number 1
Enter number of units produced by each department.
Append a negative number to the end of the list.
1 2 3 -1
Total = 6

Enter production data for plant number 2
Enter number of units produced by each department.
Append a negative number to the end of the list.
0 2 3 -1
Total = 5

Enter production data for plant number 3
Enter number of units produced by each department.
Append a negative number to the end of the list.
2 -1
Total = 2

Enter production data for plant number 4
Enter number of units produced by each department.
Append a negative number to the end of the list.
-1
Total = 0

Total production for each of plants 1 through 4:
6 5 2 0
Test Again?(Type y or n and Return): n
```

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Test Data for input_data

- Remember that input_data should be tested
  - With a plant that contains no production figures
  - With a plant having only one production figure
  - With a plant having more than one figure
  - With zero and non-zero production figures

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Algorithm for scale

- scale changes the value of the indexed variable to show the whole number of asterisks to print
  - Scale is called using
    scale (production, NUMBER_OF_PLANTS);

    and its algorithm is

```
for (int index = 0; index < size; index++)
  Divide the value of a[index] by 1,000 and round the result to the nearest integer
```

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Coding scale

- The code for scale, below, uses a function named round that must be defined as well

  -
    ```
    void scale(int a[ ], int size)
    {
         for (int index = 0; index < size; index++)
           a[index] = round (a[index] / 1000.0);
    }
    ```

Why not 1000?

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Function floor

- Function round, called by scale, uses the floor function from the cmath library
  - The floor function returns the first whole number less than its argument:

    floor (3.4) returns 3
    floor (3.9) returns 3
  - Adding 0.5 to the argument for floor is how round performs its task

    floor (3.4 + 0.5) returns 3
    floor (3.9 + 0.5) returns 4

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Testing scale

- To test scale
  - First test round
  - Scale should be tested with arguments that
    - Are 0
    - Round up
    - Round down

Display 7.7 (1)

Display 7.7 (2)

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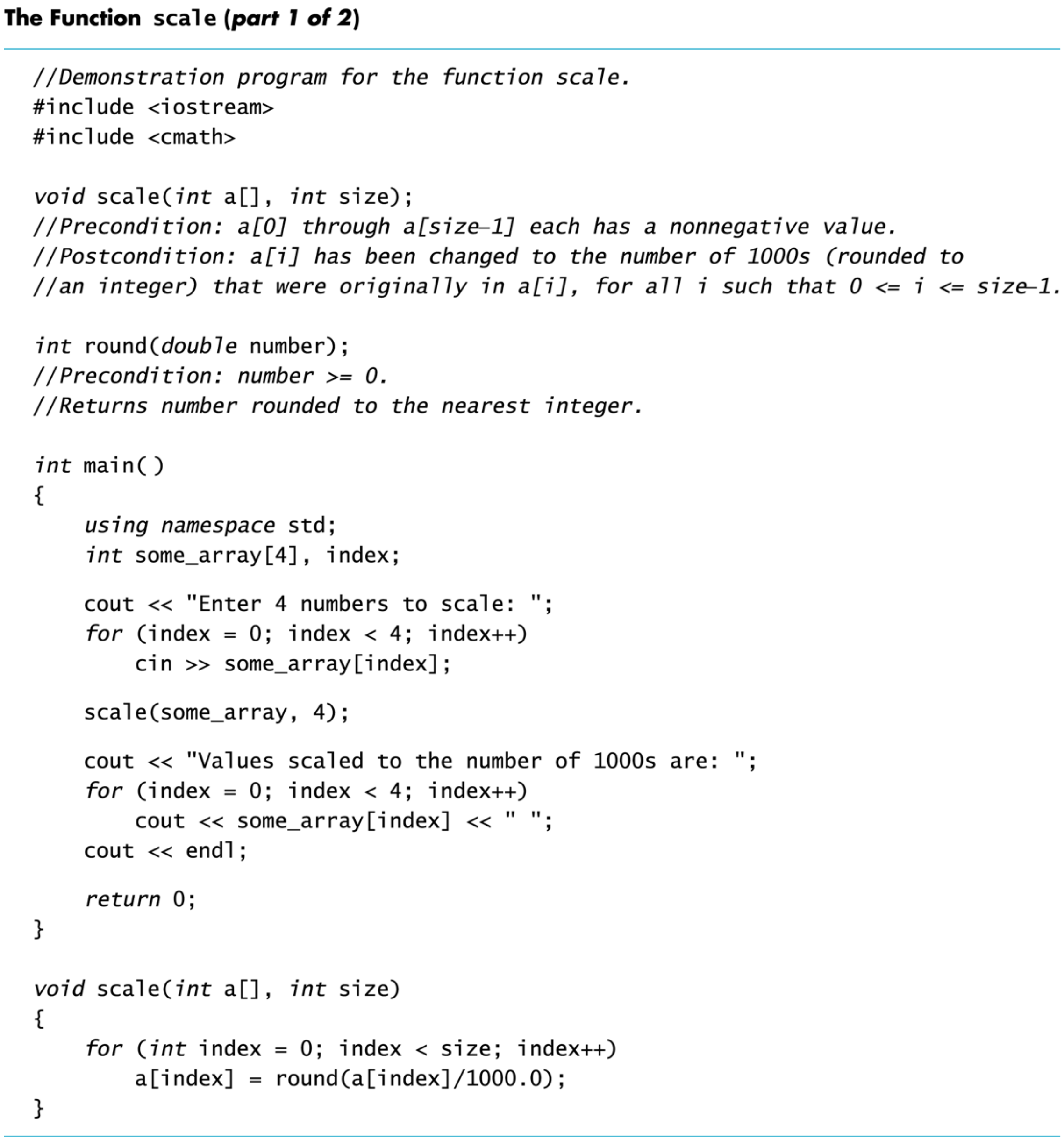
Display 7.7 (1/2)



The Function scale **(*part 1 of 2*)**

```
//Demonstration program for the function scale.
#include <iostream>
#include <cmath>

void scale(int a[], int size);
//Precondition: a[0] through a[size–1] each has a nonnegative value.
//Postcondition: a[i] has been changed to the number of 1000s (rounded to
//an integer) that were originally in a[i], for all i such that 0 <= i <= size–1.

int round(double number);
//Precondition: number >= 0.
//Returns number rounded to the nearest integer.

int main( )
{
    using namespace std;
    int some_array[4], index;

    cout << "Enter 4 numbers to scale: ";
    for (index = 0; index < 4; index++)
        cin >> some_array[index];

    scale(some_array, 4);

    cout << "Values scaled to the number of 1000s are: ";
    for (index = 0; index < 4; index++)
        cout << some_array[index] << " ";
    cout << endl;

    return 0;
}

void scale(int a[], int size)
{
    for (int index = 0; index < size; index++)
        a[index] = round(a[index]/1000.0);
}
```

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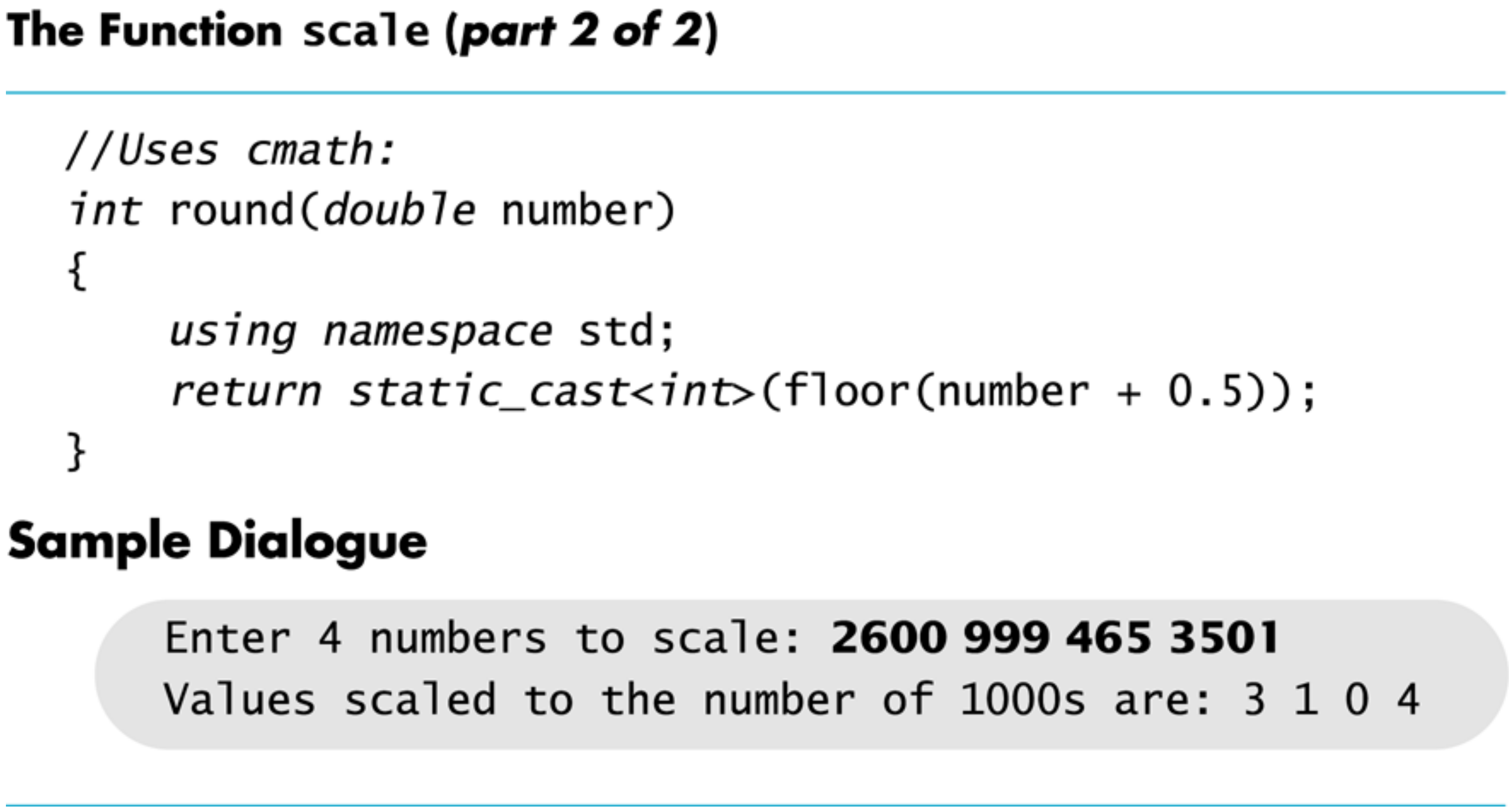
Display 7.7 (2/2)



The Function scale (*part 2 of 2*)

```
//Uses cmath:
int round(double number)
{
    using namespace std;
    return static_cast<int>(floor(number + 0.5));
}
```

Sample Dialogue

```
Enter 4 numbers to scale: 2600 999 465 3501
Values scaled to the number of 1000s are: 3 1 0 4
```

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Function graph

- The design of graph is quite straightforward and not included here

- The complete program to produce the bar graph is found in

Display 7.8 (1)

Display 7.8 (2)

Display 7.8 (3)

Display 7.8 (4)

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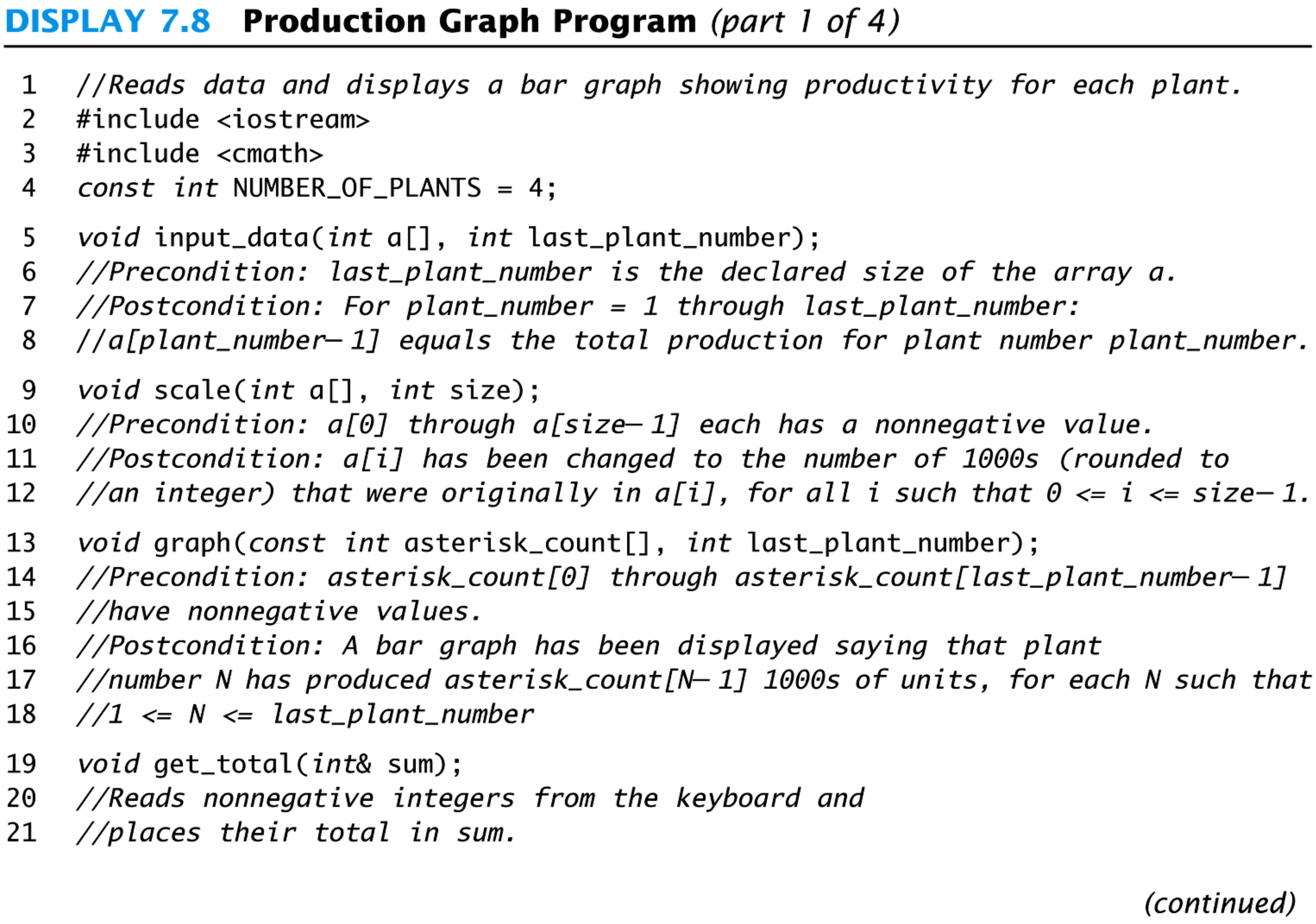
Display 7.8 (1/4)



DISPLAY 7.8 Production Graph Program *(part 1 of 4)*

```
//Reads data and displays a bar graph showing productivity for each plant.
#include <iostream>
#include <cmath>
const int NUMBER_OF_PLANTS = 4;

void input_data(int a[], int last_plant_number);
//Precondition: last_plant_number is the declared size of the array a.
//Postcondition: For plant_number = 1 through last_plant_number:
//a[plant_number– 1] equals the total production for plant number plant_number.

void scale(int a[], int size);
//Precondition: a[0] through a[size– 1] each has a nonnegative value.
//Postcondition: a[i] has been changed to the number of 1000s (rounded to
//an integer) that were originally in a[i], for all i such that 0 <= i <= size– 1.

void graph(const int asterisk_count[], int last_plant_number);
//Precondition: asterisk_count[0] through asterisk_count[last_plant_number– 1]
//have nonnegative values.
//Postcondition: A bar graph has been displayed saying that plant
//number N has produced asterisk_count[N– 1] 1000s of units, for each N such that
//1 <= N <= last_plant_number

void get_total(int& sum);
//Reads nonnegative integers from the keyboard and
//places their total in sum.
```

(continued)

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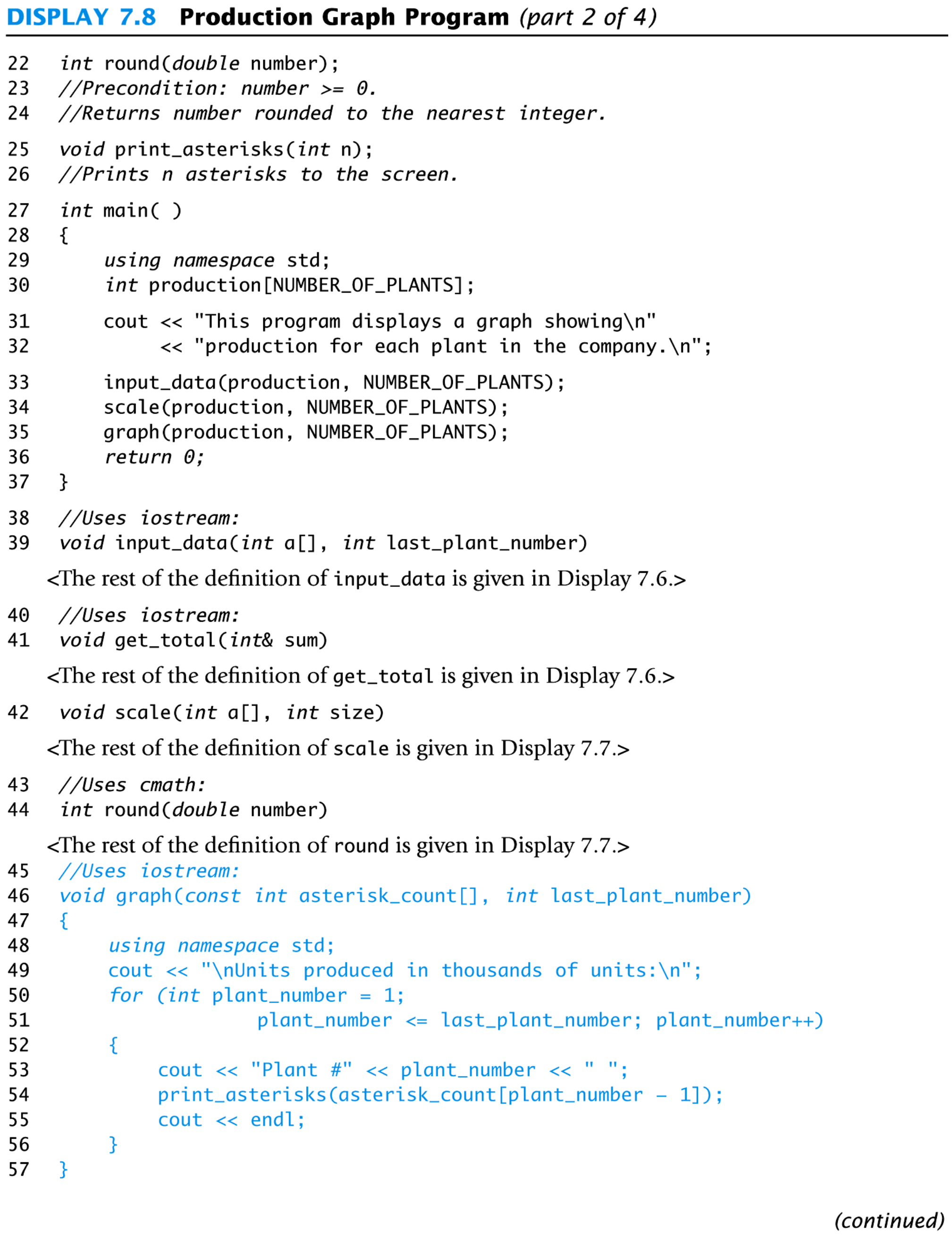
Display 7.8 (2/4)



DISPLAY 7.8 Production Graph Program *(part 2 of 4)*

```
int round(double number);
//Precondition: number >= 0.
//Returns number rounded to the nearest integer.

void print_asterisks(int n);
//Prints n asterisks to the screen.

int main( )
{
    using namespace std;
    int production[NUMBER_OF_PLANTS];

    cout << "This program displays a graph showing\n"
         << "production for each plant in the company.\n";

    input_data(production, NUMBER_OF_PLANTS);
    scale(production, NUMBER_OF_PLANTS);
    graph(production, NUMBER_OF_PLANTS);
    return 0;
}

//Uses iostream:
void input_data(int a[], int last_plant_number)
<The rest of the definition of input_data is given in Display 7.6.>

//Uses iostream:
void get_total(int& sum)
<The rest of the definition of get_total is given in Display 7.6.>

void scale(int a[], int size)
<The rest of the definition of scale is given in Display 7.7.>

//Uses cmath:
int round(double number)
<The rest of the definition of round is given in Display 7.7.>
//Uses iostream:
void graph(const int asterisk_count[], int last_plant_number)
{
    using namespace std;
    cout << "\nUnits produced in thousands of units:\n";
    for (int plant_number = 1;
                 plant_number <= last_plant_number; plant_number++)
    {
        cout << "Plant #" << plant_number << " ";
        print_asterisks(asterisk_count[plant_number - 1]);
        cout << endl;
    }
}
```

(continued)

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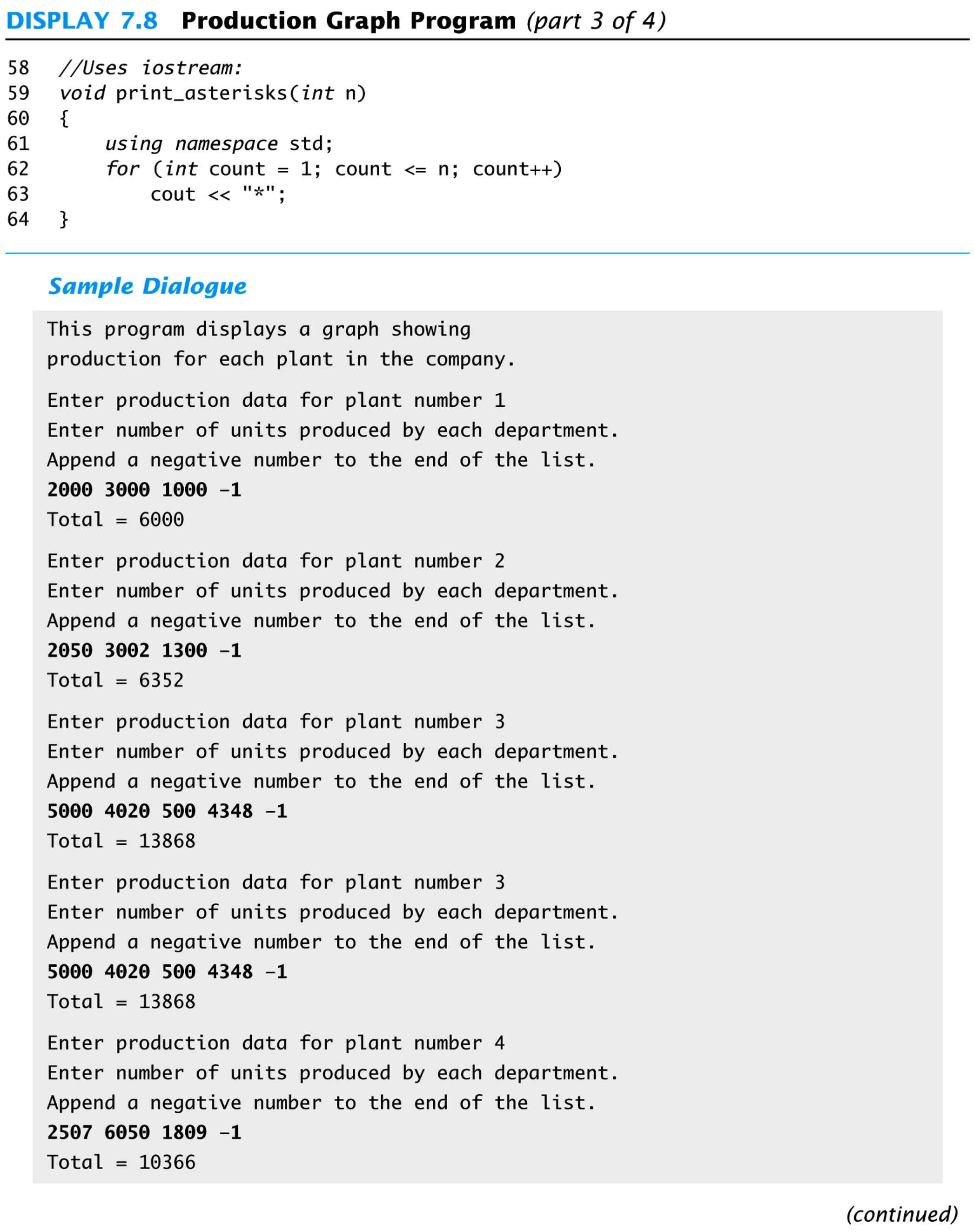
Display 7.8 (3/4)



DISPLAY 7.8 Production Graph Program *(part 3 of 4)*

```
//Uses iostream:
void print_asterisks(int n)
{
    using namespace std;
    for (int count = 1; count <= n; count++)
        cout << "*";
}
```

Sample Dialogue

```
This program displays a graph showing
production for each plant in the company.

Enter production data for plant number 1
Enter number of units produced by each department.
Append a negative number to the end of the list.
2000 3000 1000 -1
Total = 6000

Enter production data for plant number 2
Enter number of units produced by each department.
Append a negative number to the end of the list.
2050 3002 1300 -1
Total = 6352

Enter production data for plant number 3
Enter number of units produced by each department.
Append a negative number to the end of the list.
5000 4020 500 4348 -1
Total = 13868

Enter production data for plant number 3
Enter number of units produced by each department.
Append a negative number to the end of the list.
5000 4020 500 4348 -1
Total = 13868

Enter production data for plant number 4
Enter number of units produced by each department.
Append a negative number to the end of the list.
2507 6050 1809 -1
Total = 10366
```

(continued)

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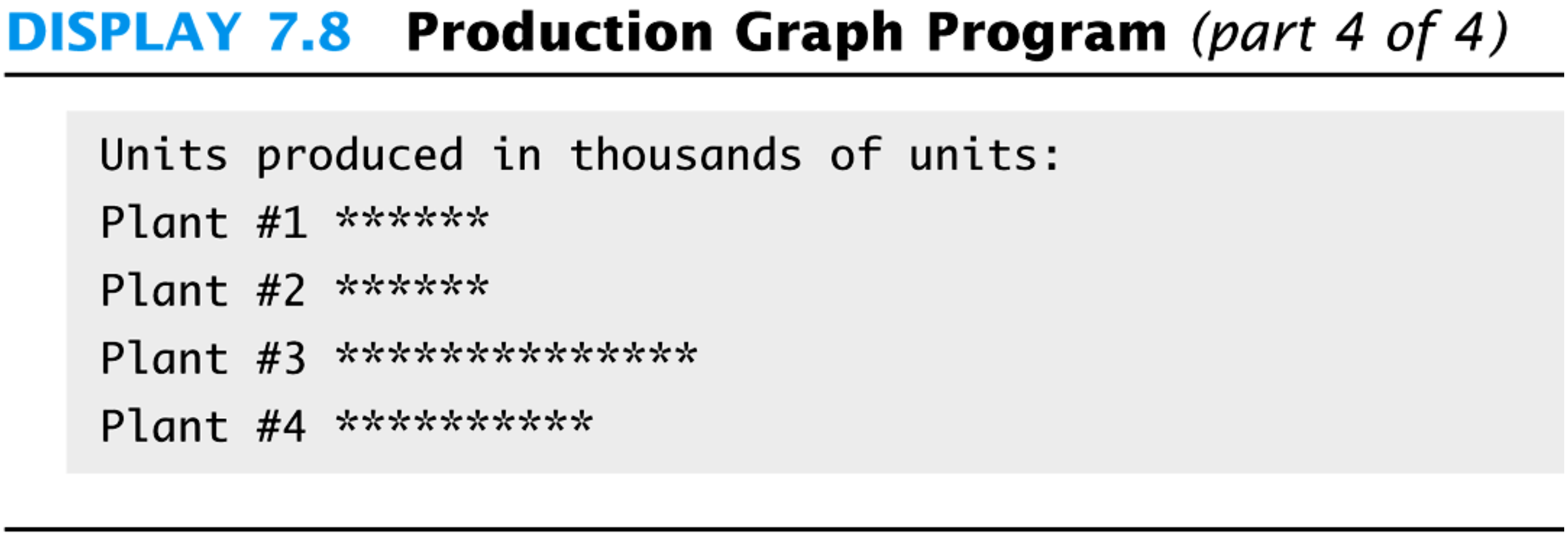
Display 7.8 (4/4)



DISPLAY 7.8 Production Graph Program *(part 4 of 4)*

```
Units produced in thousands of units:
Plant #1 ******
Plant #2 ******
Plant #3 **************
Plant #4 **********
```

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Section 7.2 Conclusion

- Can you
  - Write a function definition for a function called one_more, which has a formal parameter for an array of integers and increases the value of each array element by one. Are other formal parameters needed?

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7.3

Programming with Arrays

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Programming With Arrays

- The size needed for an array is changeable
  - Often varies from one run of a program to another
  - Is often not known when the program is written

- A common solution to the size problem
  - Declare the array size to be the largest that could be needed
  - Decide how to deal with partially filled arrays

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Partially Filled Arrays

- When using arrays that are partially filled
  - Functions dealing with the array may not need to know the declared size of the array, only how many elements are stored in the array
  - A parameter, number_used, may be sufficient to ensure that referenced index values are legal
  - A function such as fill_array in Display 7.9 needs to know the declared size of the array

Display 7.9 (1) Display 7.9 (2) Display 7.9 (3)

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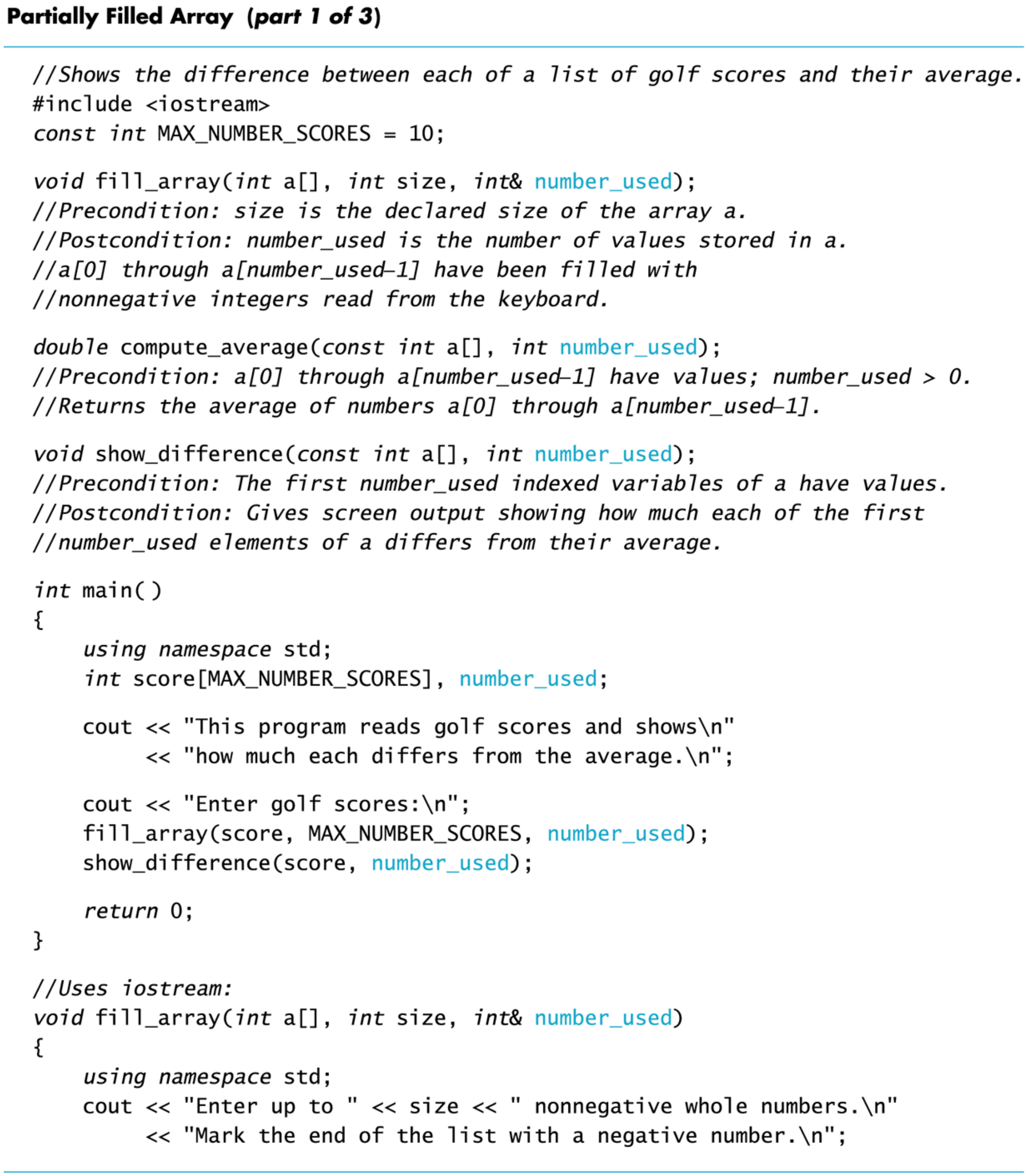
Display 7.9 (1/3)



Partially Filled Array ***(part 1 of 3)***

```
//Shows the difference between each of a list of golf scores and their average.
#include <iostream>
const int MAX_NUMBER_SCORES = 10;

void fill_array(int a[], int size, int& number_used);
//Precondition: size is the declared size of the array a.
//Postcondition: number_used is the number of values stored in a.
//a[0] through a[number_used-1] have been filled with
//nonnegative integers read from the keyboard.

double compute_average(const int a[], int number_used);
//Precondition: a[0] through a[number_used-1] have values; number_used > 0.
//Returns the average of numbers a[0] through a[number_used-1].

void show_difference(const int a[], int number_used);
//Precondition: The first number_used indexed variables of a have values.
//Postcondition: Gives screen output showing how much each of the first
//number_used elements of a differs from their average.

int main( )
{
    using namespace std;
    int score[MAX_NUMBER_SCORES], number_used;

    cout << "This program reads golf scores and shows\n"
         << "how much each differs from the average.\n";

    cout << "Enter golf scores:\n";
    fill_array(score, MAX_NUMBER_SCORES, number_used);
    show_difference(score, number_used);

    return 0;
}

//Uses iostream:
void fill_array(int a[], int size, int& number_used)
{
    using namespace std;
    cout << "Enter up to " << size << " nonnegative whole numbers.\n"
         << "Mark the end of the list with a negative number.\n";
```

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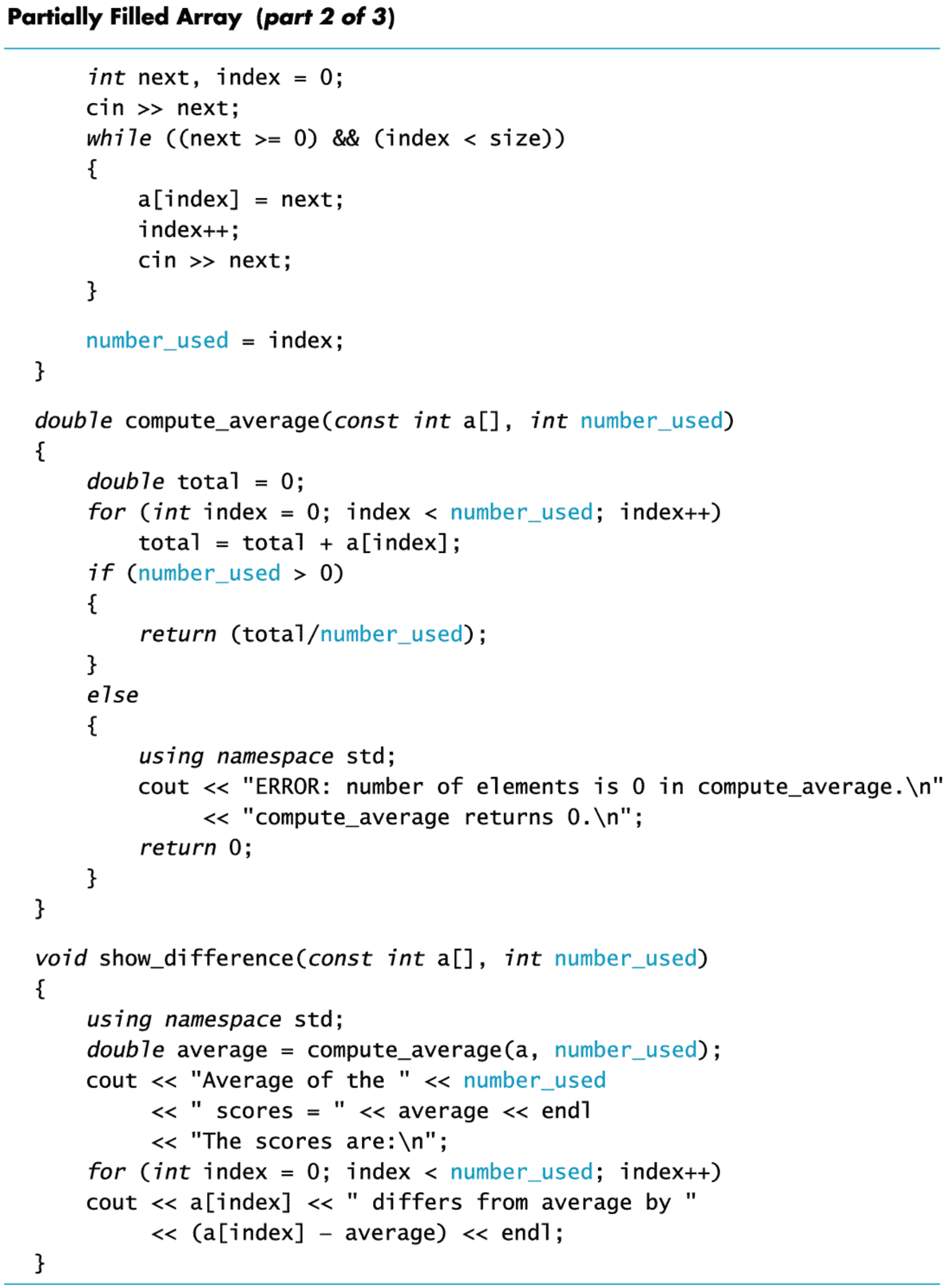
Display 7.9 (2/3)



Partially Filled Array ***(part 2 of 3)***

```
    int next, index = 0;
    cin >> next;
    while ((next >= 0) && (index < size))
    {
        a[index] = next;
        index++;
        cin >> next;
    }

    number_used = index;
}

double compute_average(const int a[], int number_used)
{
    double total = 0;
    for (int index = 0; index < number_used; index++)
        total = total + a[index];
    if (number_used > 0)
    {
        return (total/number_used);
    }
    else
    {
        using namespace std;
        cout << "ERROR: number of elements is 0 in compute_average.\n"
             << "compute_average returns 0.\n";
        return 0;
    }
}

void show_difference(const int a[], int number_used)
{
    using namespace std;
    double average = compute_average(a, number_used);
    cout << "Average of the " << number_used
         << " scores = " << average << endl
         << "The scores are:\n";
    for (int index = 0; index < number_used; index++)
    cout << a[index] << " differs from average by "
         << (a[index] - average) << endl;
}
```

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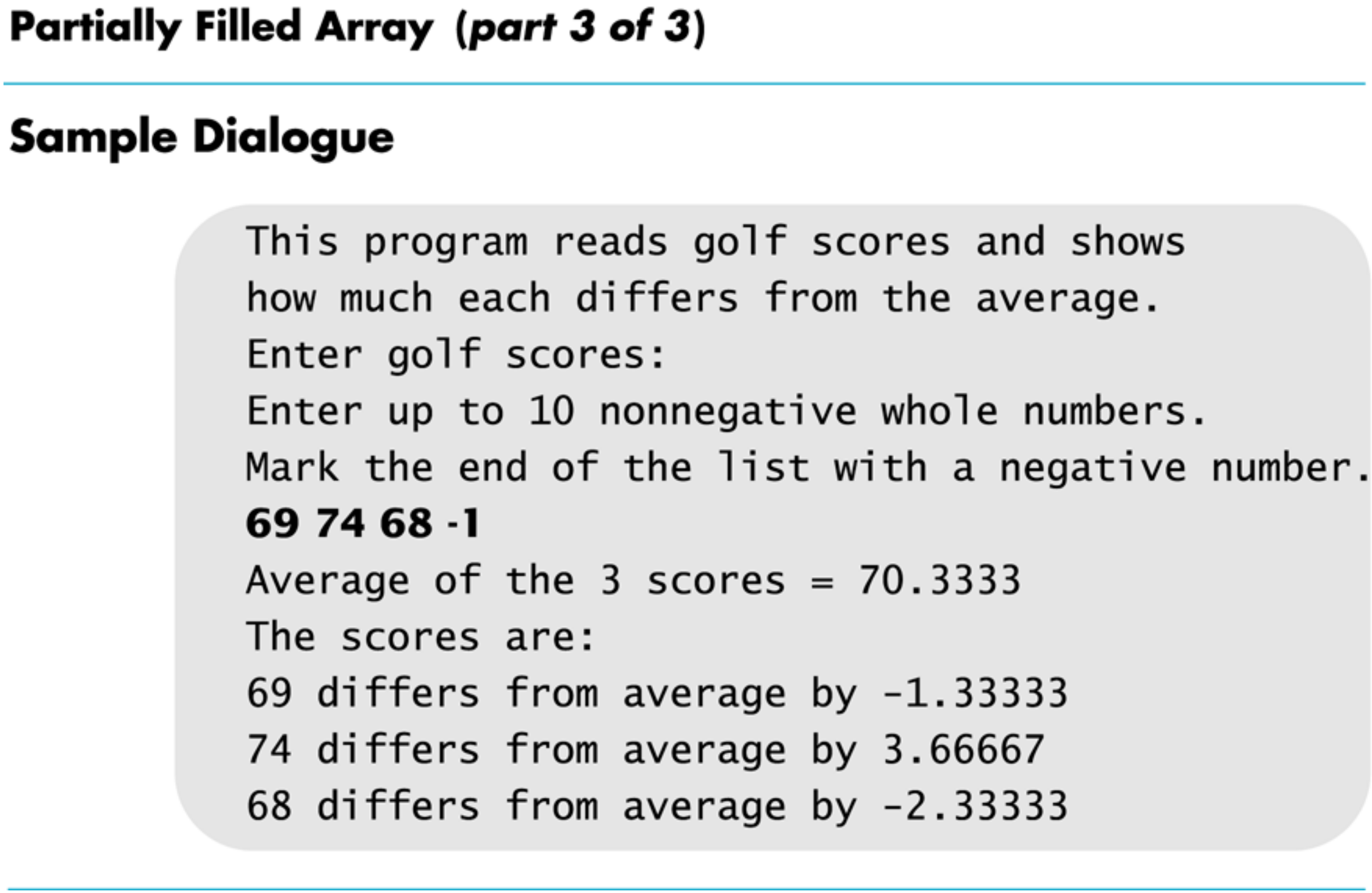
Display 7.9 (3/3)



Partially Filled Array ***(part 3 of 3)***

Sample Dialogue

```
This program reads golf scores and shows
how much each differs from the average.
Enter golf scores:
Enter up to 10 nonnegative whole numbers.
Mark the end of the list with a negative number.
69 74 68 -1
Average of the 3 scores = 70.3333
The scores are:
69 differs from average by -1.33333
74 differs from average by 3.66667
68 differs from average by -2.33333
```

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Constants as Arguments

- When function fill_array (Display 7.9) is called, MAX_NUMBER_SCORES is used as an argument
    - Can't MAX_NUMBER_SCORES be used directly without making it an argument?
        - Using MAX_NUMBER_SCORES as an argument makes it clear that fill_array requires the array's declared size
        - This makes fill_array easier to be used in other programs

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Searching Arrays

- A sequential search is one way to search an array for a given value
  - Look at each element from first to last to see if the target value is equal to any of the array elements
  - The index of the target value can be returned to indicate where the value was found in the array
  - A value of -1 can be returned if the value was not found

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The search Function

- The search function of Display 7.10…
  - Uses a while loop to compare array elements to the target value
  - Sets a variable of type bool to true if the target value is found, ending the loop
  - Checks the boolean variable when the loop ends to see if the target value was found
  - Returns the index of the target value if found, otherwise returns -1

Display 7.10 (1) **Display 7.10 (2)**

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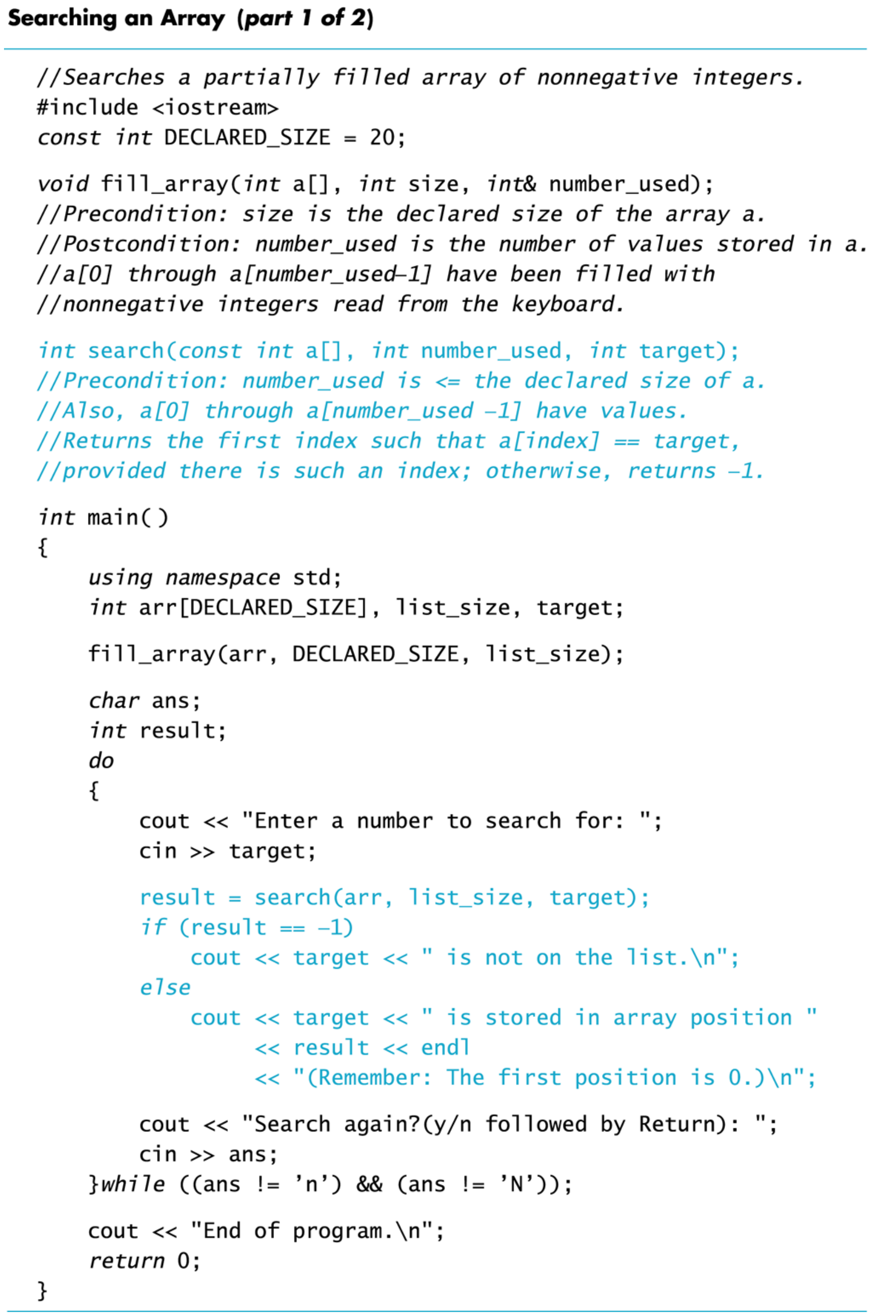
Display 7.10 (1/2)



Searching an Array ***(part 1 of 2)***

```
//Searches a partially filled array of nonnegative integers.
#include <iostream>
const int DECLARED_SIZE = 20;

void fill_array(int a[], int size, int& number_used);
//Precondition: size is the declared size of the array a.
//Postcondition: number_used is the number of values stored in a.
//a[0] through a[number_used–1] have been filled with
//nonnegative integers read from the keyboard.

int search(const int a[], int number_used, int target);
//Precondition: number_used is <= the declared size of a.
//Also, a[0] through a[number_used –1] have values.
//Returns the first index such that a[index] == target,
//provided there is such an index; otherwise, returns –1.

int main( )
{
    using namespace std;
    int arr[DECLARED_SIZE], list_size, target;

    fill_array(arr, DECLARED_SIZE, list_size);

    char ans;
    int result;
    do
    {
        cout << "Enter a number to search for: ";
        cin >> target;

        result = search(arr, list_size, target);
        if (result == –1)
            cout << target << " is not on the list.\n";
        else
            cout << target << " is stored in array position "
                 << result << endl
                 << "(Remember: The first position is 0.)\n";

        cout << "Search again?(y/n followed by Return): ";
        cin >> ans;
    }while ((ans != 'n') && (ans != 'N'));

    cout << "End of program.\n";
    return 0;
}
```

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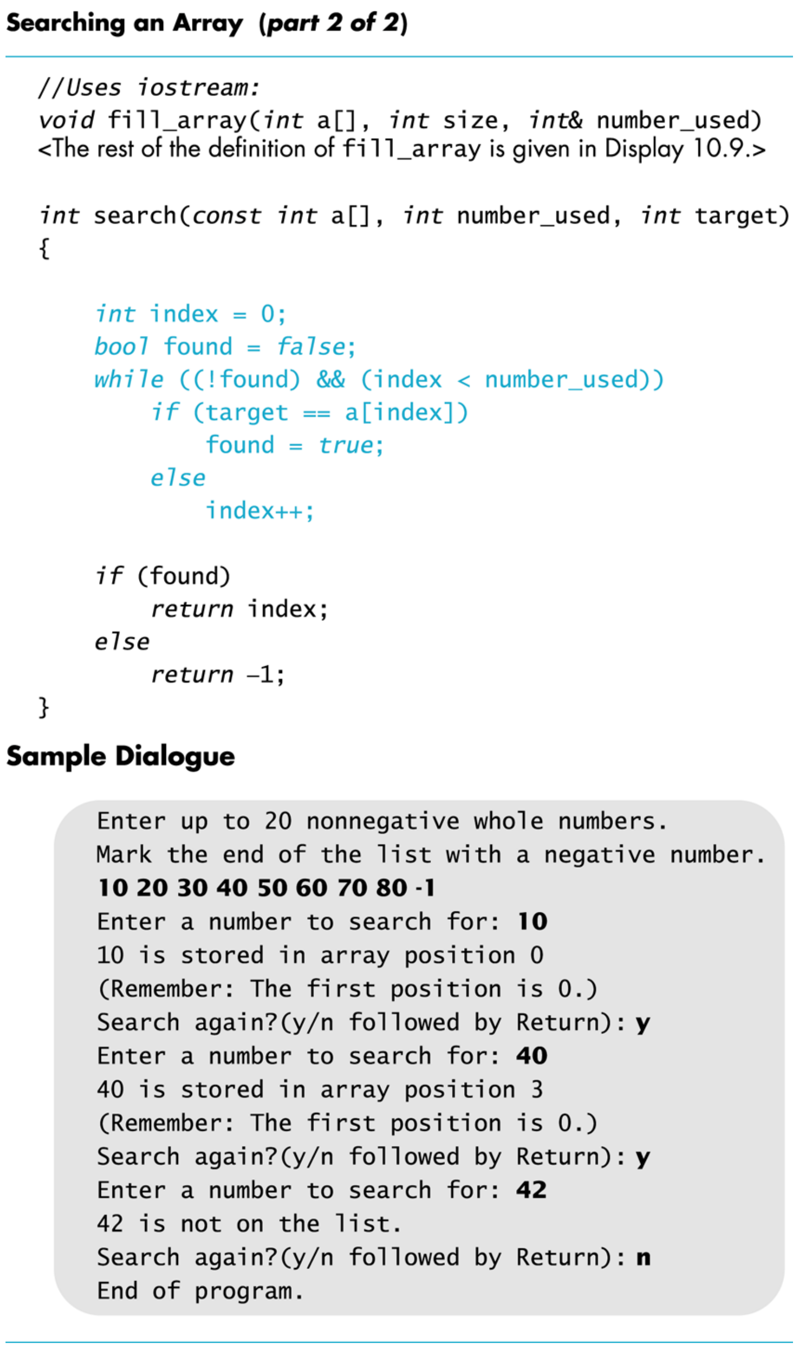
Display 7.10 (2/2)



Searching an Array ***(part 2 of 2)***

```
//Uses iostream:
void fill_array(int a[], int size, int& number_used)
<The rest of the definition of fill_array is given in Display 10.9.>

int search(const int a[], int number_used, int target)
{

    int index = 0;
    bool found = false;
    while ((!found) && (index < number_used))
        if (target == a[index])
            found = true;
        else
            index++;

    if (found)
        return index;
    else
        return -1;
}
```

Sample Dialogue

```
Enter up to 20 nonnegative whole numbers.
Mark the end of the list with a negative number.
10 20 30 40 50 60 70 80 -1
Enter a number to search for: 10
10 is stored in array position 0
(Remember: The first position is 0.)
Search again?(y/n followed by Return): y
Enter a number to search for: 40
40 is stored in array position 3
(Remember: The first position is 0.)
Search again?(y/n followed by Return): y
Enter a number to search for: 42
42 is not on the list.
Search again?(y/n followed by Return): n
End of program.
```

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Program Example: Sorting an Array

- Sorting a list of values is very common task
  - Create an alphabetical listing
  - Create a list of values in ascending order
  - Create a list of values in descending order
- Many sorting algorithms exist
  - Some are very efficient
  - Some are easier to understand

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Program Example: The Selection Sort Algorithm

- When the sort is complete, the elements of the array are ordered such that

  a[0] < a[1] < … < a [number_used -1]

  - This leads to an outline of an algorithm:

```
for (int index = 0; index < number_used; index++)
      place the indexth smallest element in a[index]
```

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Program Example: Sort Algorithm Development

- One array is sufficient to do our sorting
  - Search for the smallest value in the array
  - Place this value in a[0], and place the value that was in a[0] in the location where the smallest was found
  - Starting at a[1], find the smallest remaining value swap it with the value currently in a[1]
  - Starting at a[2], continue the process until the array is sorted

Display 7.11 **Display 7.12 (1-2)**

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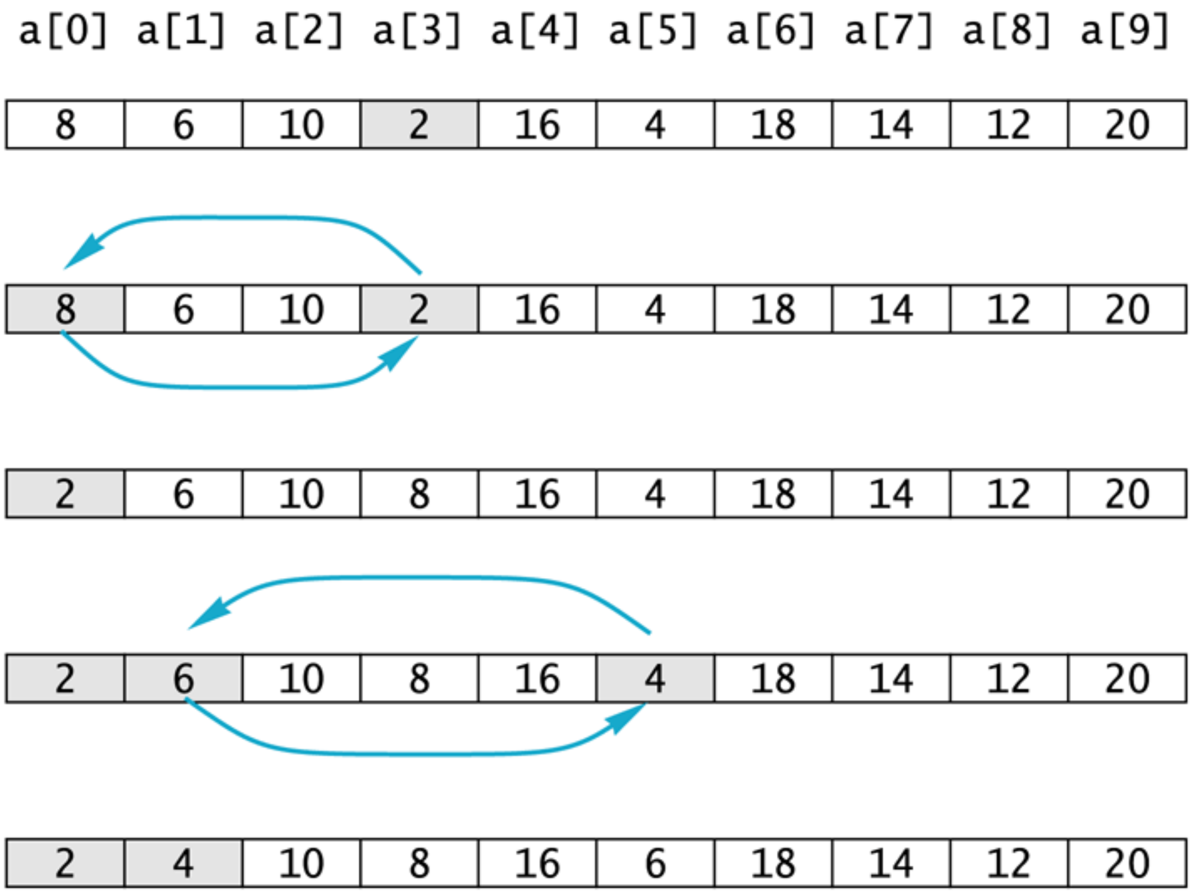
Display 7.11

Selection Sort



a[0]	a[1]	a[2]	a[3]	a[4]	a[5]	a[6]	a[7]	a[8]	a[9]
8	6	10	2	16	4	18	14	12	20
8	6	10	2	16	4	18	14	12	20
2	6	10	8	16	4	18	14	12	20
2	6	10	8	16	4	18	14	12	20
2	4	10	8	16	6	18	14	12	20

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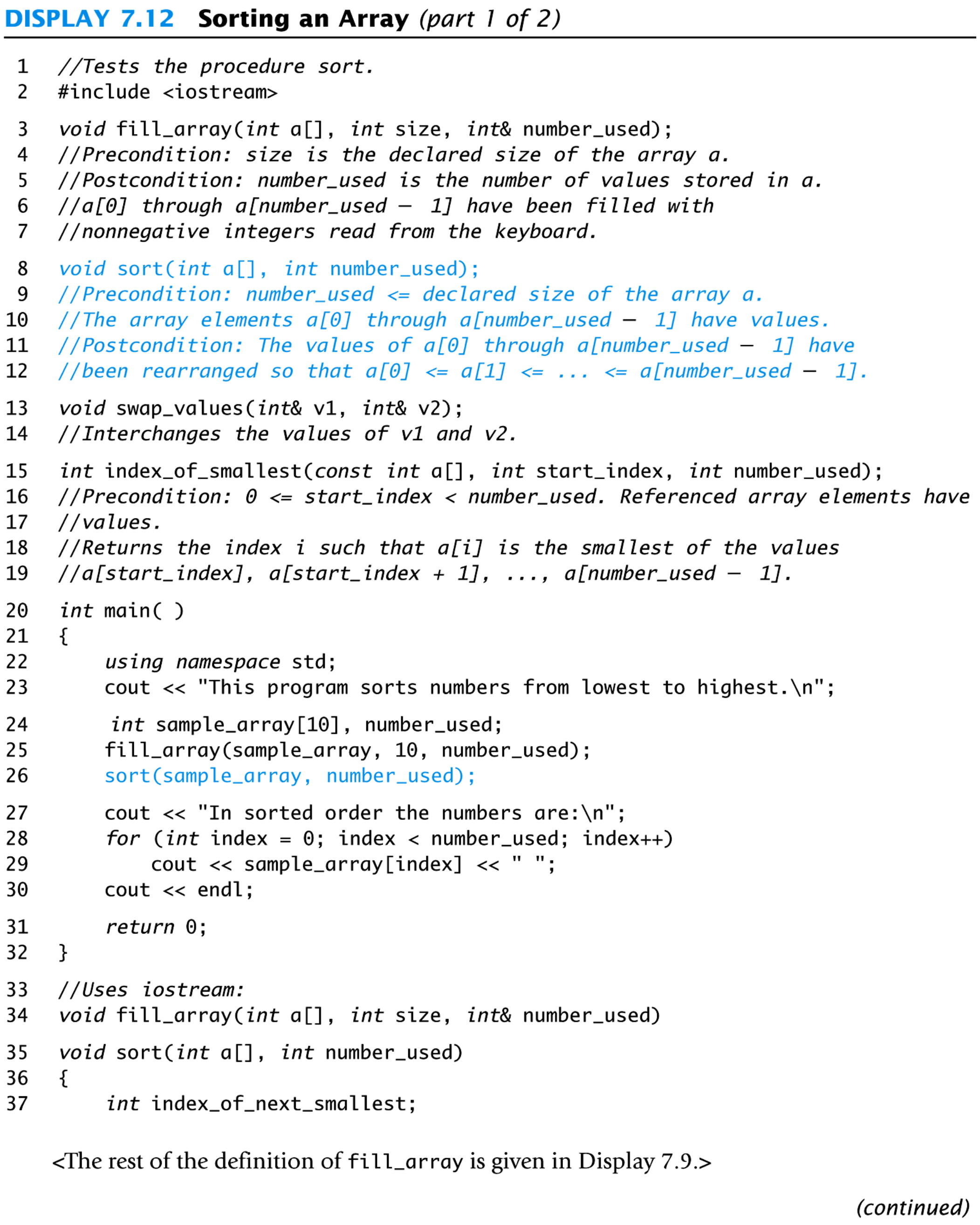
Display 7.12 (1/2)



DISPLAY 7.12 Sorting an Array *(part 1 of 2)*

```
//Tests the procedure sort.
#include <iostream>

void fill_array(int a[], int size, int& number_used);
//Precondition: size is the declared size of the array a.
//Postcondition: number_used is the number of values stored in a.
//a[0] through a[number_used – 1] have been filled with
//nonnegative integers read from the keyboard.

void sort(int a[], int number_used);
//Precondition: number_used <= declared size of the array a.
//The array elements a[0] through a[number_used – 1] have values.
//Postcondition: The values of a[0] through a[number_used – 1] have
//been rearranged so that a[0] <= a[1] <= ... <= a[number_used – 1].

void swap_values(int& v1, int& v2);
//Interchanges the values of v1 and v2.

int index_of_smallest(const int a[], int start_index, int number_used);
//Precondition: 0 <= start_index < number_used. Referenced array elements have
//values.
//Returns the index i such that a[i] is the smallest of the values
//a[start_index], a[start_index + 1], ..., a[number_used – 1].

int main( )
{
    using namespace std;
    cout << "This program sorts numbers from lowest to highest.\n";

    int sample_array[10], number_used;
    fill_array(sample_array, 10, number_used);
    sort(sample_array, number_used);

    cout << "In sorted order the numbers are:\n";
    for (int index = 0; index < number_used; index++)
        cout << sample_array[index] << " ";
    cout << endl;

    return 0;
}

//Uses iostream:
void fill_array(int a[], int size, int& number_used)

void sort(int a[], int number_used)
{
    int index_of_next_smallest;
```

<The rest of the definition of fill_array is given in Display 7.9.>

(continued)

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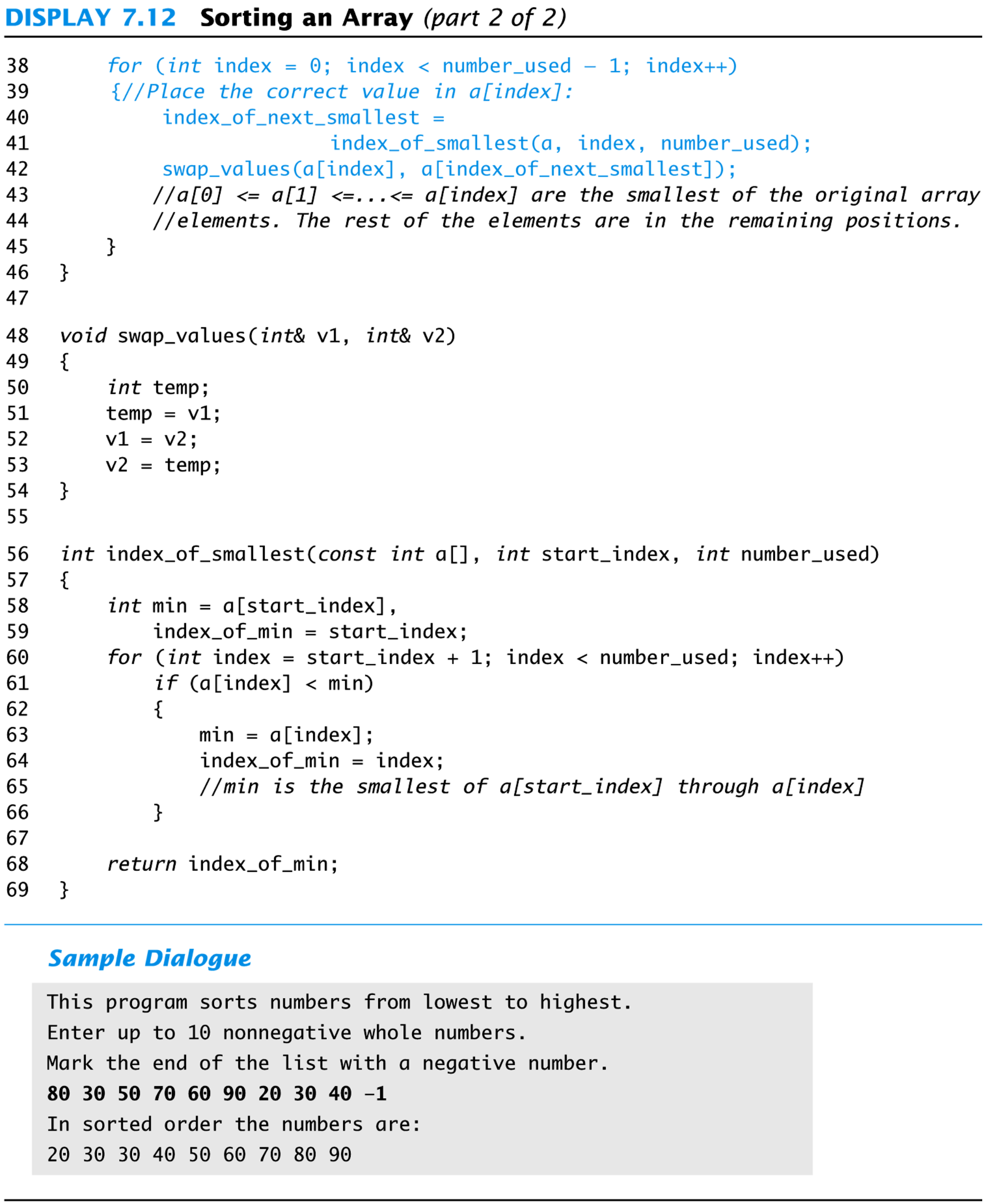
Display 7.12 (2/2)



DISPLAY 7.12 **Sorting an Array** *(part 2 of 2)*

```
    for (int index = 0; index < number_used - 1; index++)
    {//Place the correct value in a[index]:
         index_of_next_smallest =
                      index_of_smallest(a, index, number_used);
         swap_values(a[index], a[index_of_next_smallest]);
        //a[0] <= a[1] <=...<= a[index] are the smallest of the original array
        //elements. The rest of the elements are in the remaining positions.
    }
}

void swap_values(int& v1, int& v2)
{
    int temp;
    temp = v1;
    v1 = v2;
    v2 = temp;
}

int index_of_smallest(const int a[], int start_index, int number_used)
{
    int min = a[start_index],
        index_of_min = start_index;
    for (int index = start_index + 1; index < number_used; index++)
        if (a[index] < min)
        {
            min = a[index];
            index_of_min = index;
            //min is the smallest of a[start_index] through a[index]
        }

    return index_of_min;
}
```

Sample Dialogue

```
This program sorts numbers from lowest to highest.
Enter up to 10 nonnegative whole numbers.
Mark the end of the list with a negative number.
80 30 50 70 60 90 20 30 40 -1
In sorted order the numbers are:
20 30 30 40 50 60 70 80 90
```

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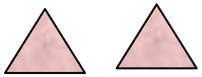
Program Example: Bubble Sort

- There are many sorting algorithms, another simple one is Bubble Sort
- Idea is to bubble the largest value toward the end of the array by swapping consecutive elements
- Initial array:

3, 10, 9, 2, 5



- Compare 3 and 10; no swap since 10 is greater than 3

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Program Example: Bubble Sort

3, 10, 9, 2, 5

- Compare 10 and 9; swap since 10 is larger than 9

3, 9, 10, 2, 5

- Compare 10 and 2; swap since 10 is larger than 2

3, 9, 2, 10, 5

- Compare 10 and 5; swap since 10 is larger than 5

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Program Example: Bubble Sort

3, 9, 2, 5, 10

- We have now “bubbled” the largest value, 10, to the right of the array
- The algorithm now repeats the process but stops at the position to the left of 10

3, 9, 2, 5, 10

Bubble largest value between index 0-3 here

- Implementation requires nested loops

Display 7.13

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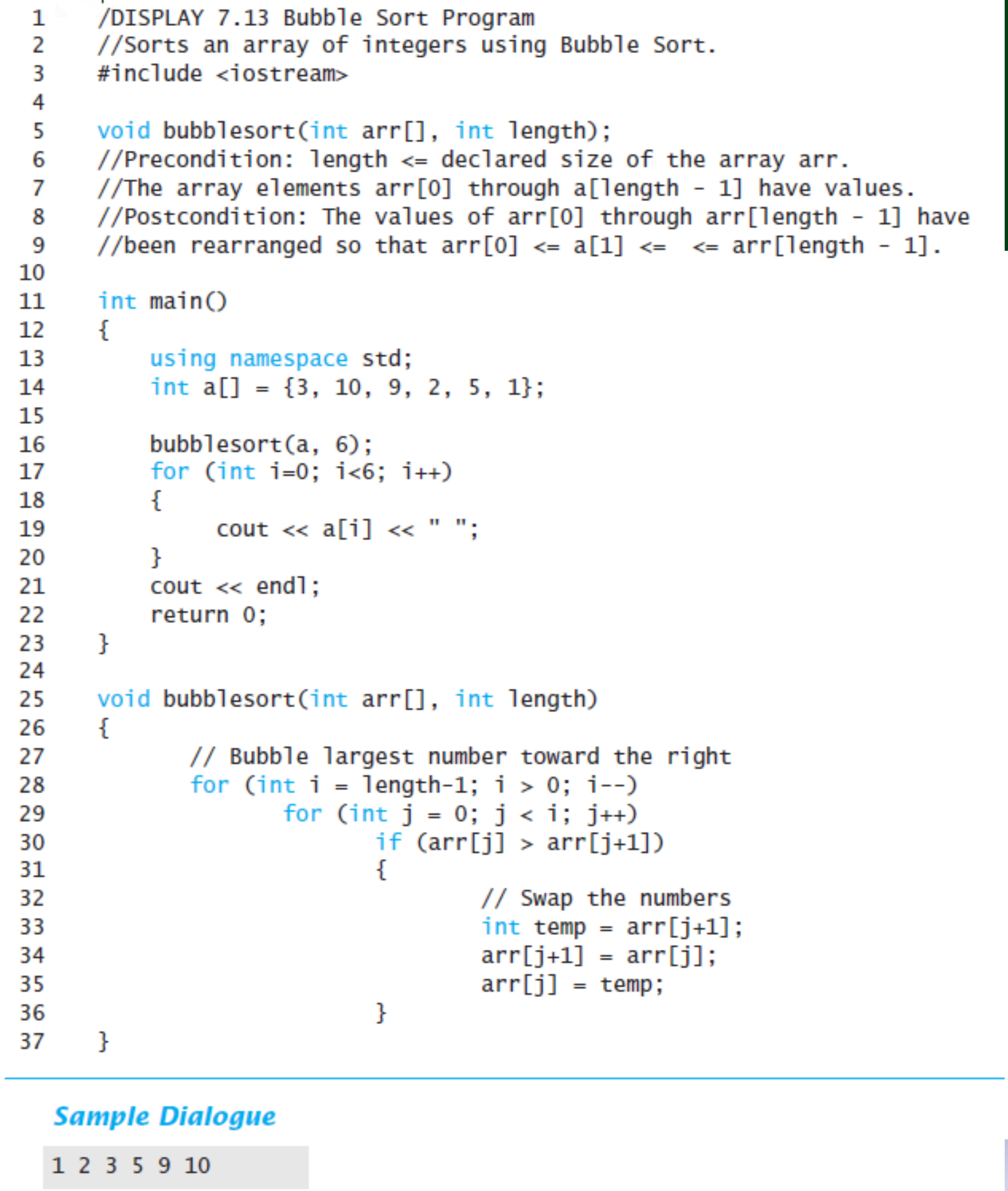
Display 7.13



```
/DISPLAY 7.13 Bubble Sort Program
//Sorts an array of integers using Bubble Sort.
#include <iostream>

void bubblesort(int arr[], int length);
//Precondition: length <= declared size of the array arr.
//The array elements arr[0] through a[length - 1] have values.
//Postcondition: The values of arr[0] through arr[length - 1] have
//been rearranged so that arr[0] <= a[1] <=  <= arr[length - 1].

int main()
{
    using namespace std;
    int a[] = {3, 10, 9, 2, 5, 1};

    bubblesort(a, 6);
    for (int i=0; i<6; i++)
    {
         cout << a[i] << " ";
    }
    cout << endl;
    return 0;
}

void bubblesort(int arr[], int length)
{
       // Bubble largest number toward the right
       for (int i = length-1; i > 0; i--)
              for (int j = 0; j < i; j++)
                     if (arr[j] > arr[j+1])
                     {
                             // Swap the numbers
                             int temp = arr[j+1];
                             arr[j+1] = arr[j];
                             arr[j] = temp;
                     }
}
```

Sample Dialogue

```
1 2 3 5 9 10
```

Section 7.3 Conclusion

- Can you
  - Write a program that will read up to 10 letters into an array and write the letters back to the screen in the reverse order?

    abcd should be output as dcba

    Use a period as a sentinel value to mark the end of input

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7.4

Multidimensional Arrays

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Multi-Dimensional Arrays

- C++ allows arrays with multiple index values
  - char page [30] [100];
    declares an array of characters named page
    - page has two index values:
      The first ranges from 0 to 29
      The second ranges from 0 to 99
  - Each index in enclosed in its own brackets
  - Page can be visualized as an array of
    30 rows and 100 columns

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Index Values of page

- The indexed variables for array page are
  page[0][0], page[0][1], …, page[0][99]
  page[1][0], page[1][1], …, page[1][99]
- …
  page[29][0], page[29][1], … , page[29][99]

- page is actually an array of size 30
  - page's base type is an array of 100 characters

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Multidimensional Array Parameters

- Recall that the size of an array is not needed when declaring a formal parameter:

  ```
  void display_line(const char a[ ], int size);
  ```

- The base type of a multi-dimensional array must be completely specified in the parameter declaration

  -
    ```
    void display_page(const char page[ ] [100],
                                          int size_dimension_1);
    ```

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Program Example: Grading Program

- Grade records for a class can be stored in a two-dimensional array
  - For a class with 4 students and 3 quizzes the array could be declared as

    ```
    int grade[4][3];
    ```

    - The first array index refers to the number of a student
    - The second array index refers to a quiz number
- Since student and quiz numbers start with one, we subtract one to obtain the correct index

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Grading Program: average scores

- The grading program uses one-dimensional arrays to store…
  - Each student's average score
  - Each quiz's average score
- The functions that calculate these averages use global constants for the size of the arrays
  - This was done because the functions seem to be particular to this program

Display 7.14 (1-3)

Display 7.15

Display 7.16

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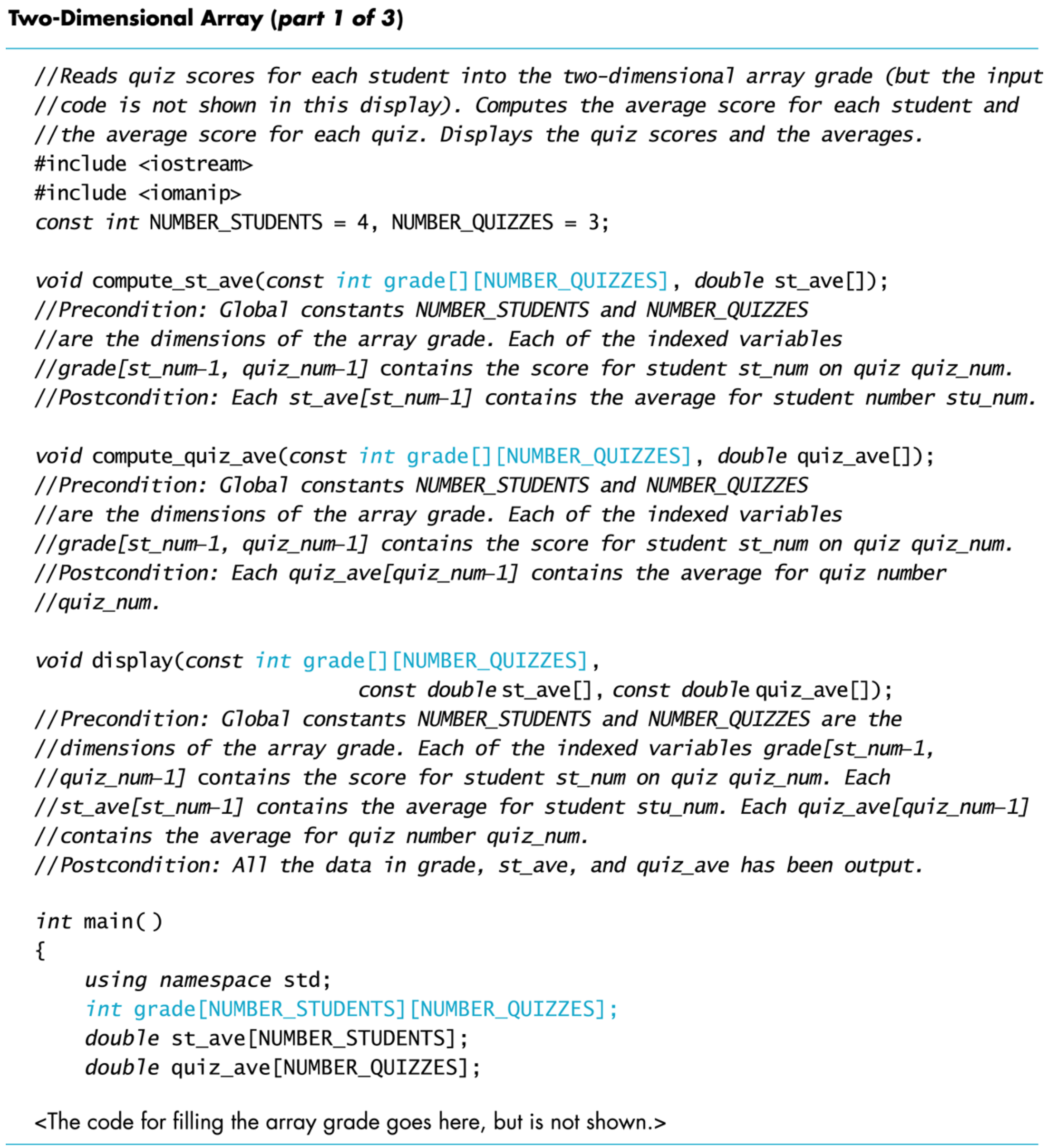
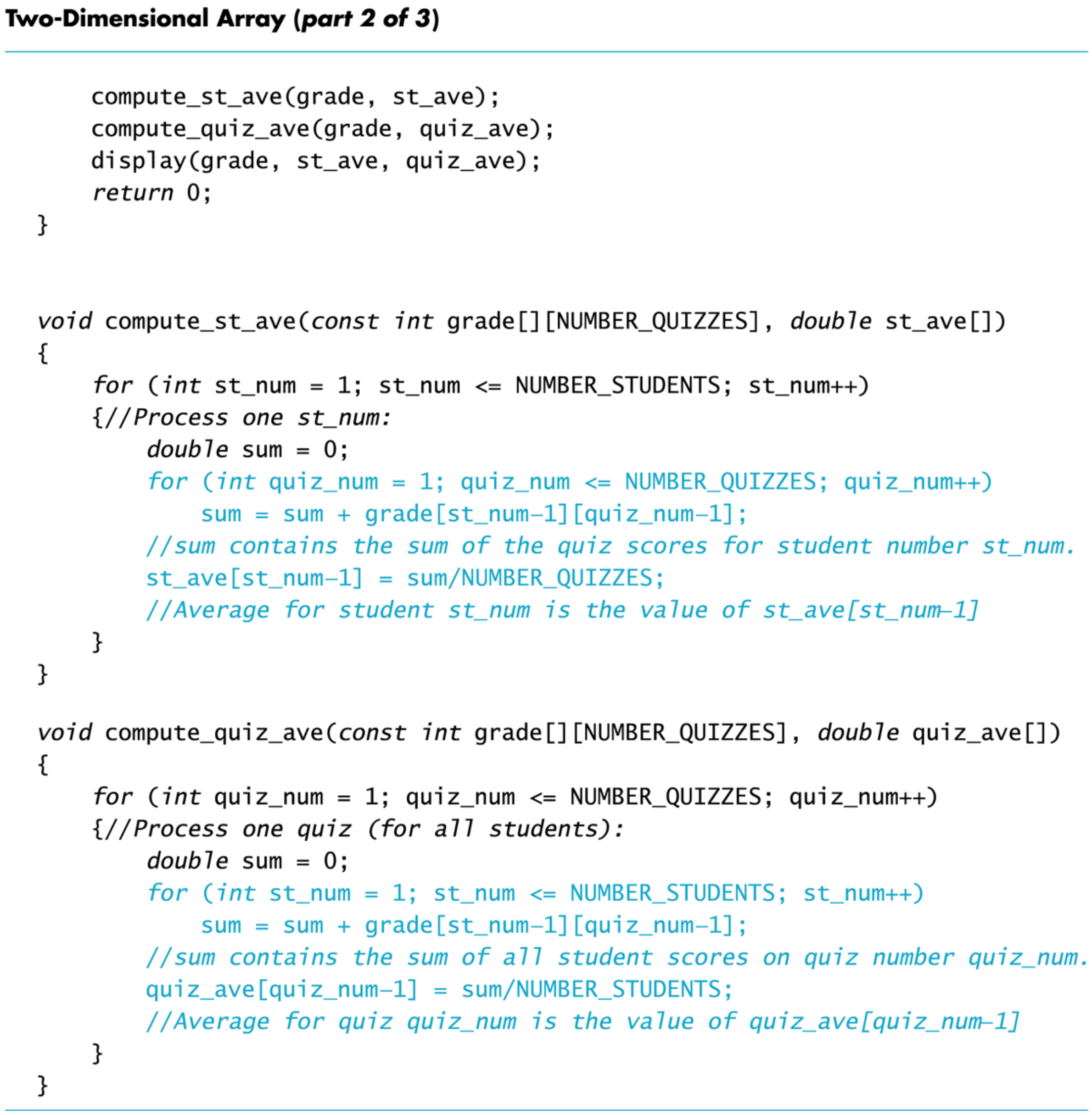
Display 7.14 (1/3)



Two-Dimensional Array (*part 1 of 3*)

```
//Reads quiz scores for each student into the two-dimensional array grade (but the input
//code is not shown in this display). Computes the average score for each student and
//the average score for each quiz. Displays the quiz scores and the averages.
#include <iostream>
#include <iomanip>
const int NUMBER_STUDENTS = 4, NUMBER_QUIZZES = 3;

void compute_st_ave(const int grade[][NUMBER_QUIZZES], double st_ave[]);
//Precondition: Global constants NUMBER_STUDENTS and NUMBER_QUIZZES
//are the dimensions of the array grade. Each of the indexed variables
//grade[st_num-1, quiz_num-1] contains the score for student st_num on quiz quiz_num.
//Postcondition: Each st_ave[st_num-1] contains the average for student number stu_num.

void compute_quiz_ave(const int grade[][NUMBER_QUIZZES], double quiz_ave[]);
//Precondition: Global constants NUMBER_STUDENTS and NUMBER_QUIZZES
//are the dimensions of the array grade. Each of the indexed variables
//grade[st_num-1, quiz_num-1] contains the score for student st_num on quiz quiz_num.
//Postcondition: Each quiz_ave[quiz_num-1] contains the average for quiz number
//quiz_num.

void display(const int grade[][NUMBER_QUIZZES],
                            const double st_ave[], const double quiz_ave[]);
//Precondition: Global constants NUMBER_STUDENTS and NUMBER_QUIZZES are the
//dimensions of the array grade. Each of the indexed variables grade[st_num-1,
//quiz_num-1] contains the score for student st_num on quiz quiz_num. Each
//st_ave[st_num-1] contains the average for student stu_num. Each quiz_ave[quiz_num-1]
//contains the average for quiz number quiz_num.
//Postcondition: All the data in grade, st_ave, and quiz_ave has been output.

int main( )
{
    using namespace std;
    int grade[NUMBER_STUDENTS][NUMBER_QUIZZES];
    double st_ave[NUMBER_STUDENTS];
    double quiz_ave[NUMBER_QUIZZES];

<The code for filling the array grade goes here, but is not shown.>
```

Display 7.14 (2/3)



Two-Dimensional Array (*part 2 of 3*)

```
    compute_st_ave(grade, st_ave);
    compute_quiz_ave(grade, quiz_ave);
    display(grade, st_ave, quiz_ave);
    return 0;
}


void compute_st_ave(const int grade[][NUMBER_QUIZZES], double st_ave[])
{
    for (int st_num = 1; st_num <= NUMBER_STUDENTS; st_num++)
    {//Process one st_num:
        double sum = 0;
        for (int quiz_num = 1; quiz_num <= NUMBER_QUIZZES; quiz_num++)
            sum = sum + grade[st_num-1][quiz_num-1];
        //sum contains the sum of the quiz scores for student number st_num.
        st_ave[st_num-1] = sum/NUMBER_QUIZZES;
        //Average for student st_num is the value of st_ave[st_num-1]
    }
}

void compute_quiz_ave(const int grade[][NUMBER_QUIZZES], double quiz_ave[])
{
    for (int quiz_num = 1; quiz_num <= NUMBER_QUIZZES; quiz_num++)
    {//Process one quiz (for all students):
        double sum = 0;
        for (int st_num = 1; st_num <= NUMBER_STUDENTS; st_num++)
            sum = sum + grade[st_num-1][quiz_num-1];
        //sum contains the sum of all student scores on quiz number quiz_num.
        quiz_ave[quiz_num-1] = sum/NUMBER_STUDENTS;
        //Average for quiz quiz_num is the value of quiz_ave[quiz_num-1]
    }
}
```

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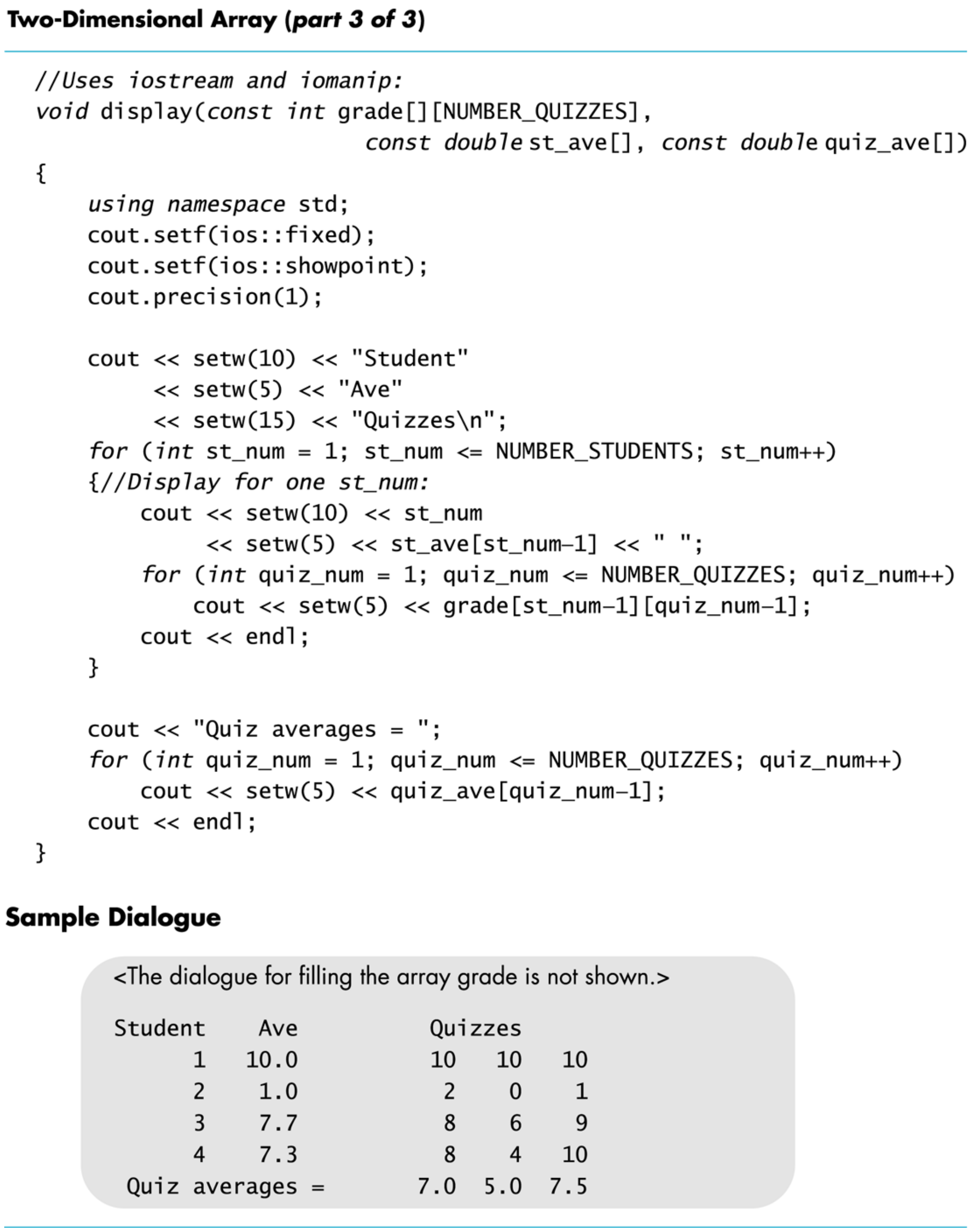
Display 7.14 (3/3)



Two-Dimensional Array (*part 3 of 3*)

```
//Uses iostream and iomanip:
void display(const int grade[][NUMBER_QUIZZES],
                         const double st_ave[], const double quiz_ave[])
{
    using namespace std;
    cout.setf(ios::fixed);
    cout.setf(ios::showpoint);
    cout.precision(1);

    cout << setw(10) << "Student"
         << setw(5) << "Ave"
         << setw(15) << "Quizzes\n";
    for (int st_num = 1; st_num <= NUMBER_STUDENTS; st_num++)
    {//Display for one st_num:
        cout << setw(10) << st_num
             << setw(5) << st_ave[st_num-1] << " ";
        for (int quiz_num = 1; quiz_num <= NUMBER_QUIZZES; quiz_num++)
            cout << setw(5) << grade[st_num-1][quiz_num-1];
        cout << endl;
    }

    cout << "Quiz averages = ";
    for (int quiz_num = 1; quiz_num <= NUMBER_QUIZZES; quiz_num++)
        cout << setw(5) << quiz_ave[quiz_num-1];
    cout << endl;
}
```

Sample Dialogue

<The dialogue for filling the array grade is not shown.>

```
Student    Ave         Quizzes
      1   10.0         10   10   10
      2    1.0          2    0    1
      3    7.7          8    6    9
      4    7.3          8    4   10
 Quiz averages =       7.0  5.0  7.5
```

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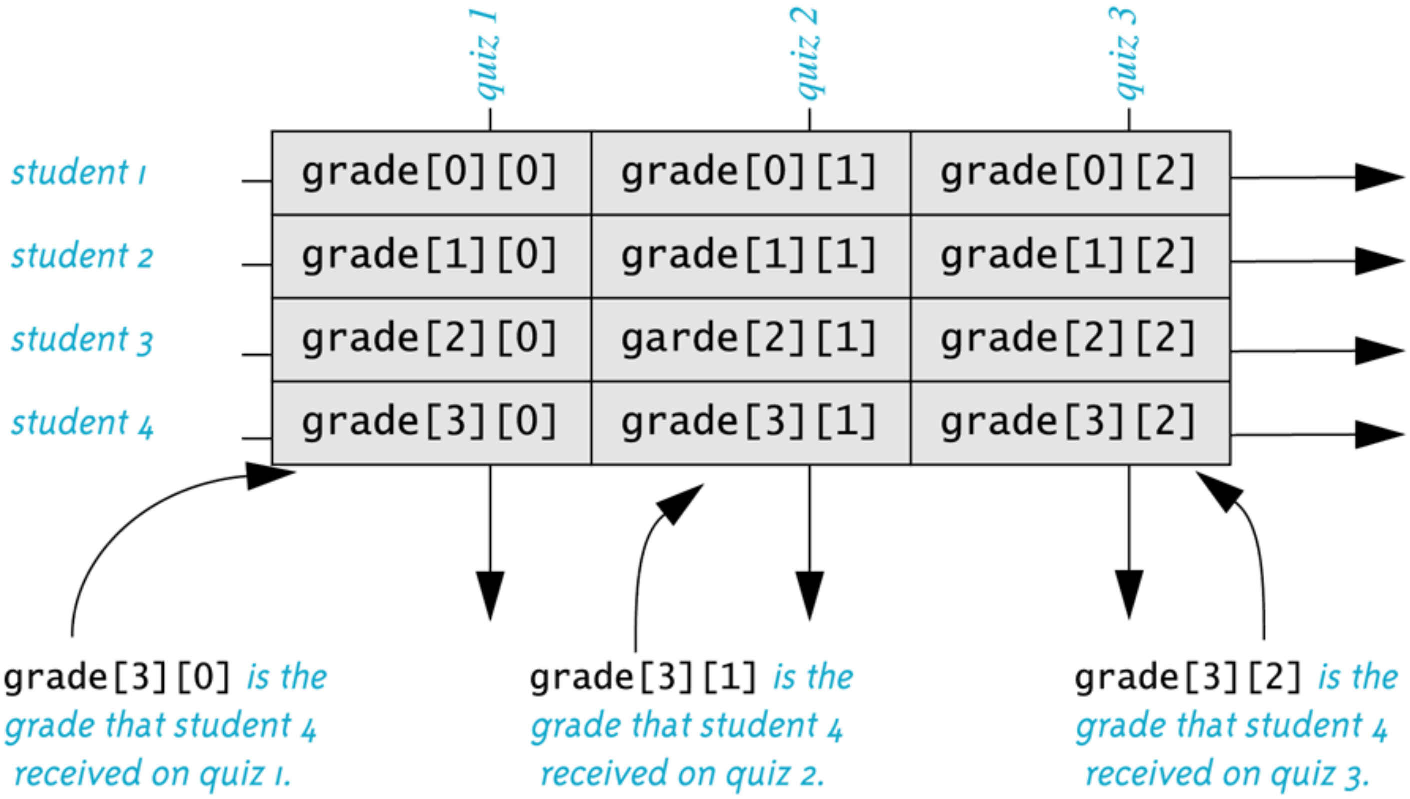
Display 7.15

The Two-Dimensional Array grade



	quiz 1	*quiz 2*	*quiz 3*
student 1	grade[0][0]	grade[0][1]	grade[0][2]
student 2	grade[1][0]	grade[1][1]	grade[1][2]
student 3	grade[2][0]	garde[2][1]	grade[2][2]
student 4	grade[3][0]	grade[3][1]	grade[3][2]

grade[3][0] *is the grade that student 4 received on quiz 1.*

grade[3][1] *is the grade that student 4 received on quiz 2.*

grade[3][2] *is the grade that student 4 received on quiz 3.*

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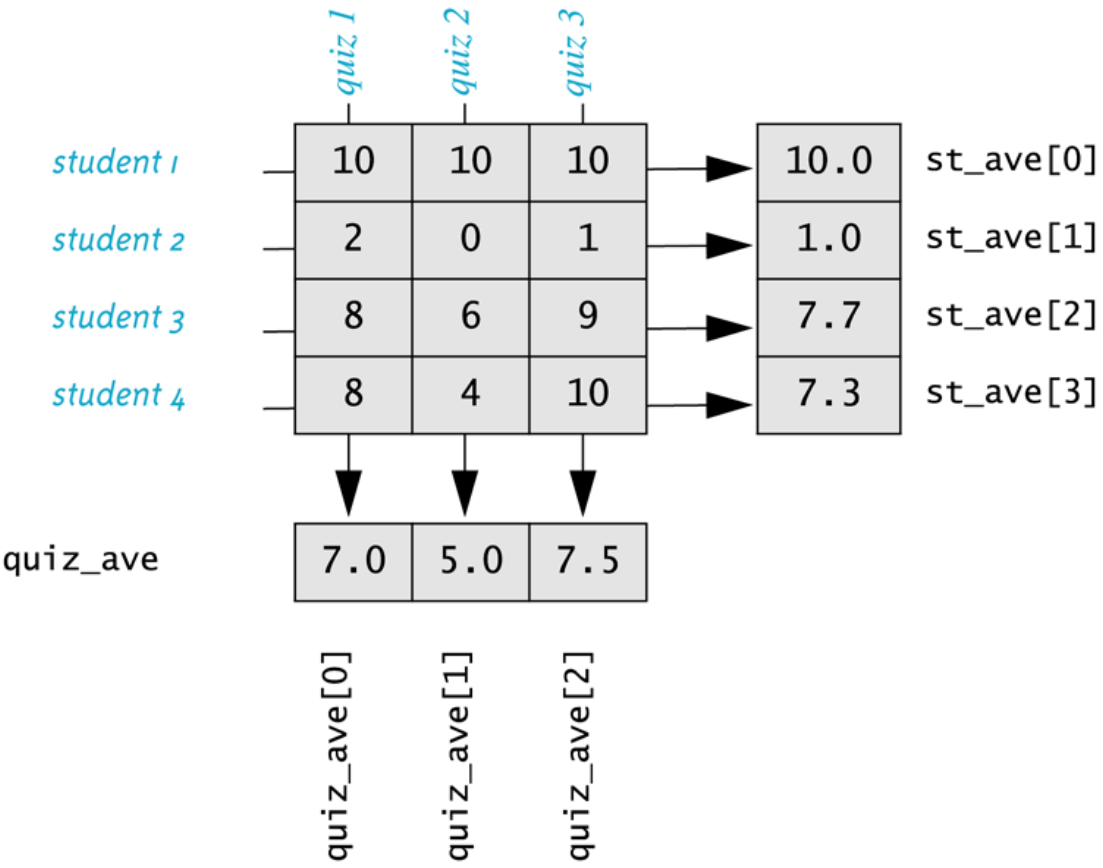
Display 7.16

The Two-Dimensional Array grade (Another View)



	quiz 1	quiz 2	quiz 3		
student 1	10	10	10	10.0	st_ave[0]
student 2	2	0	1	1.0	st_ave[1]
student 3	8	6	9	7.7	st_ave[2]
student 4	8	4	10	7.3	st_ave[3]
quiz_ave	7.0	5.0	7.5		
	quiz_ave[0]	quiz_ave[1]	quiz_ave[2]		

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Section 7.5 Conclusion

- Can you
  - Write code that will fill the array a(declared below) with numbers typed at the keyboard? The numbers will be input fiver per line, on four lines.

```
int a[4][5];
```

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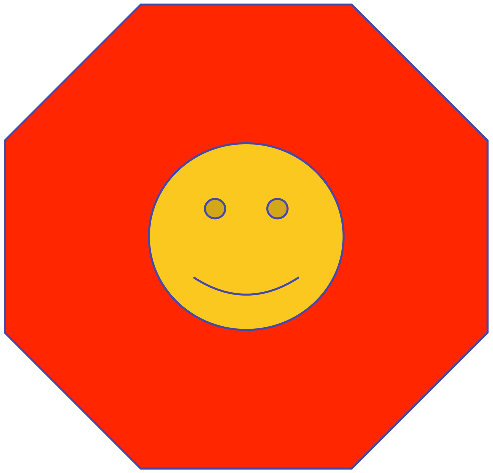
Chapter 7 - End



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