Chapter 4 - Arrays

Outline

4.1 Introduction

- Arrays
  - Structures of related data items
  - Static entity (same size throughout program)
- A few types
  - Pointer-based arrays (C-like)
  - Arrays as objects (C++)

4.2 Arrays

- Array
  - Consecutive group of memory locations
  - Same name and type (**`int`**, **`char`**, etc.)
- To refer to an element
  - Specify array name and position number (index)
  - Format: arrayname[position number]
  - First element at position 0
- N-element array c

  `c[ 0 ]`, **`c[ 1 ]`** … **`c[ n - 1 ]`**
  - Nth element as position N-1

4.2 Arrays

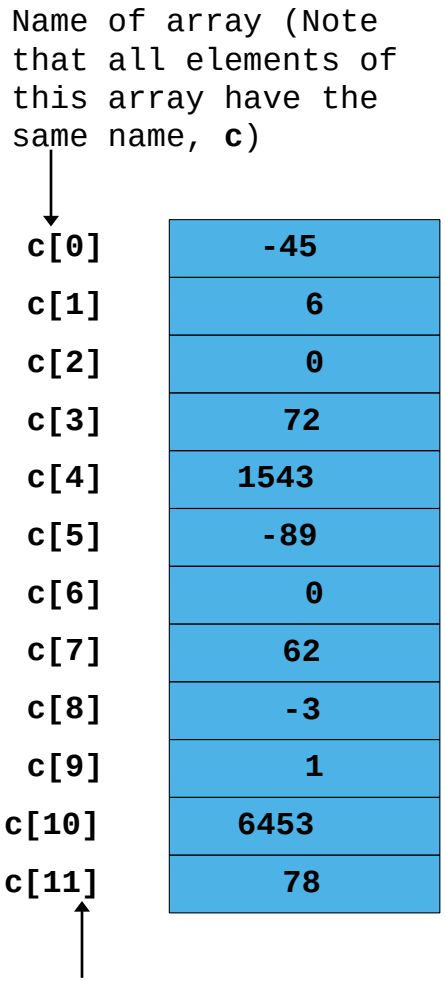
- Array elements like other variables
  - Assignment, printing for an integer array **c**

```
c[ 0 ] =  3;
cout << c[ 0 ];
```

- Can perform operations inside subscript

  c[5 - 2] same as **c[3]**

4.2 Arrays



4.3 Declaring Arrays

- When declaring arrays, specify
  - Name
  - Type of array
    - Any data type
  - Number of elements
  - *type arrayName*`[` *arraySize* `];`

```
int c[ 10 ];  // array of 10 integers
float d[ 3284 ]; // array of 3284 floats
```

- Declaring multiple arrays of same type
  - Use comma separated list, like regular variables

```
int b[ 100 ], x[ 27 ];
```


4.4 Examples Using Arrays

- Initializing arrays
  - For loop
    - Set each element
  - Initializer list
    - Specify each element when array declared

```
int n[ 5 ] = { 1, 2, 3, 4, 5 };
```

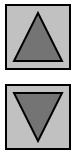
    - If not enough initializers, rightmost elements 0
    - If too many syntax error
  - To set every element to same value

```
int n[ 5 ] = { 0 };
```

  - If array size omitted, initializers determine size

```
int n[] = { 1, 2, 3, 4, 5 };
```

    - 5 initializers, therefore 5 element array



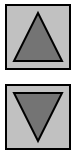
Outline

fig04_03.cpp
(1 of 2)

```
1  // Fig. 4.3: fig04_03.cpp
2  // Initializing an array.
3  #include <iostream>
4
5  using std::cout;
6  using std::endl;
7
8  #include <iomanip>
9
10 using std::setw;
11
12 int main()
13 {
14    int n[ 10 ];  // n is an array o
15
16    // initialize elements of array
17    for ( int i = 0; i < 10; i++ )
18       n[ i ] = 0;   // set element at location i to 0
19
20    cout << "Element" << setw( 13 ) << "Value" << endl;
21
22    // output contents of array n in tabular format
23    for ( int j = 0; j < 10; j++ )
24       cout << setw( 7 ) << j << setw( 13 ) << n[ j ] << endl;
25
```

Declare a 10-element array of integers.

Initialize array to **0** using a for loop. Note that the array has elements **n[0]** to **n[9]**.



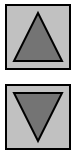
Outline

```
26    return 0;  // indicates successful termination
27
28 } // end main
```

```
Element         Value
      0             0
      1             0
      2             0
      3             0
      4             0
      5             0
      6             0
      7             0
      8             0
      9             0
```

fig04_03.cpp (2 of 2)

fig04_03.cpp output (1 of 1)

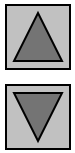


Outline

fig04_04.cpp
(1 of 1)

```
1  // Fig. 4.4: fig04_04.cpp
2  // Initializing an array with a declaration.
3  #include <iostream>
4
5  using std::cout;
6  using std::endl;
7
8  #include <iomanip>
9
10 using std::setw;
11
12 int main()
13 {
14    // use initializer list to initialize array n
15    int n[ 10 ] = { 32, 27, 64, 18, 95, 14, 90, 70, 60, 37 };
16
17    cout << "Element" << setw( 13 ) << "Value" << endl;
18
19    // output contents of array n in tabular format
20    for ( int i = 0; i < 10; i++ )
21       cout << setw( 7 ) << i << setw( 13 ) << n[ i ] << endl;
22
23    return 0;  // indicates successful termination
24
25 } // end main
```

Note the use of the initializer list.



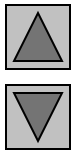
Outline

fig04_04.cpp
output (1 of 1)

```
Element         Value
      0            32
      1            27
      2            64
      3            18
      4            95
      5            14
      6            90
      7            70
      8            60
      9            37
```

4.4 Examples Using Arrays

- Array size
  - Can be specified with constant variable (**`const`**)
    - **`const int size = 20;`**
  - Constants cannot be changed
  - Constants must be initialized when declared
  - Also called named constants or read-only variables



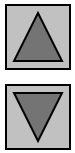
Outline

fig04_05.cpp
(1 of 2)

```
1  // Fig. 4.5: fig04_05.cpp
2  // Initialize array s to the even integers from 2 to 20.
3  #include <iostream>
4
5  using std::cout;
6  using std::endl;
7
8  #include <iomanip>
9
10 using std::setw;
11
12 int main()
13 {
14    // constant variable can be used to
15    const int arraySize = 10;
16
17    int s[ arraySize ];  // array s has 10 e
18
19    for ( int i = 0; i < arraySize; i++ )  //
20       s[ i ] = 2 + 2 * i;
21
22    cout << "Element" << setw( 13 ) << "Value
23
```

Note use of **`const`** keyword. Only **`const`** variables can specify array sizes.

The program becomes more scalable when we set the array size using a **`const`** variable. We can change **`arraySize`**, and all the loops will still work (otherwise, we'd have to update every loop in the program).



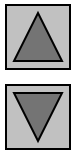
Outline

```
24    // output contents of array s in tabular format
25    for ( int j = 0; j < arraySize; j++ )
26       cout << setw( 7 ) << j << setw( 13 ) << s[ j ] << endl;
27
28    return 0;  // indicates successful termination
29
30 } // end main
```

fig04_05.cpp
(2 of 2)

fig04_05.cpp
output (1 of 1)

```
Element         Value
      0             2
      1             4
      2             6
      3             8
      4            10
      5            12
      6            14
      7            16
      8            18
      9            20
```



Outline

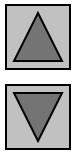
fig04_06.cpp (1 of 1)

fig04_06.cpp output (1 of 1)

```
1  // Fig. 4.6: fig04_06.cpp
2  // Using a properly initialized constant variable.
3  #include <iostream>
4
5  using std::cout;
6  using std::endl;
7
8  int main()
9  {
10    const int x = 7;  // initialized constant variable
11
12    cout << "The value of constant variable x is: "
13         << x << endl;
14
15    return 0;  // indicates successful termination
16
17 } // end main
```

Proper initialization of **`const`** variable.

```
The value of constant variable x is: 7
```



Outline

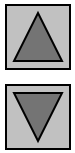
fig04_07.cpp (1 of 1)

fig04_07.cpp output (1 of 1)

```
1  // Fig. 4.7: fig04_07.cpp
2  // A const object must be initialized
3
4  int main()
5  {
6     const int x;  // Error: x must be initialized
7
8     x = 7;        // Error: cannot modify a const variable
9
10    return 0;     // indicates successful termination
11
12 } // end main
```

Uninitialized **const** results in a syntax error. Attempting to modify the **const** is another error.

```
d:\cpphtp4_examples\ch04\Fig04_07.cpp(6) : error C2734: 'x' :
   const object must be initialized if not extern
d:\cpphtp4_examples\ch04\Fig04_07.cpp(8) : error C2166:
   l-value specifies const object
```



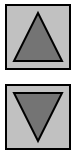
Outline

fig04_08.cpp (1 of 1)

fig04_08.cpp output (1 of 1)

```
1  // Fig. 4.8: fig04_08.cpp
2  // Compute the sum of the elements of the array.
3  #include <iostream>
4
5  using std::cout;
6  using std::endl;
7
8  int main()
9  {
10    const int arraySize = 10;
11
12    int a[ arraySize ] = { 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 };
13
14    int total = 0;
15
16    // sum contents of array a
17    for ( int i = 0; i < arraySize; i++ )
18       total += a[ i ];
19
20    cout << "Total of array element values is " << total << endl;
21
22    return 0;  // indicates successful termination
23
24 } // end main
```

```
Total of array element values is 55
```

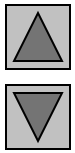


Outline

fig04_09.cpp
(1 of 2)

```
1  // Fig. 4.9: fig04_09.cpp
2  // Histogram printing program.
3  #include <iostream>
4
5  using std::cout;
6  using std::endl;
7
8  #include <iomanip>
9
10 using std::setw;
11
12 int main()
13 {
14    const int arraySize = 10;
15    int n[ arraySize ] = { 19, 3, 15, 7, 11, 9, 13, 5, 17, 1 };
16
17    cout << "Element" << setw( 13 ) << "Value"
18         << setw( 17 ) << "Histogram" << endl;
19
20    // for each element of array n, output a bar in histogram
21    for ( int i = 0; i < arraySize; i++ ) {
22       cout << setw( 7 ) << i << setw( 13 )
23            << n[ i ] << setw( 9 );
24
25       for ( int j = 0; j < n[ i ]; j++ )   // print one bar
26          cout << '*';
```

Prints asterisks corresponding to size of array element, **n[i]**.



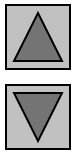
Outline

```
27
28       cout << endl;  // start next line of output
29
30    } // end outer for structure
31
32    return 0;  // indicates successful termination
33
34 } // end main
```

```
Element         Value         Histogram
      0            19         ********************
      1             3         ***
      2            15         ***************
      3             7         *******
      4            11         ***********
      5             9         *********
      6            13         *************
      7             5         *****
      8            17         *****************
      9             1         *
```

fig04_09.cpp
(2 of 2)

fig04_09.cpp
output (1 of 1)



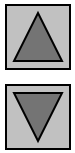
Outline

fig04_10.cpp
(1 of 2)

```
1  // Fig. 4.10: fig04_10.cpp
2  // Roll a six-sided die 6000 times.
3  #include <iostream>
4
5  using std::cout;
6  using std::endl;
7
8  #include <iomanip>
9
10 using std::setw;
11
12 #include <cstdlib>
13 #include <ctime>
14
15 int main()
16 {
17    const int arraySize = 7;
18    int frequency[ arraySize ] = { 0 };
19
20    srand( time( 0 ) );  // seed random-number
21
22    // roll die 6000 times
23    for ( int roll = 1; roll <= 6000; roll++ )
24       ++frequency[ 1 + rand() % 6 ]; // replac
25                                      // of Fig
```

Remake of old program to roll dice. An array is used instead of 6 regular variables, and the proper element can be updated easily (without needing a **`switch`**).

This creates a number between 1 and 6, which determines the index of **`frequency[]`** that should be incremented.



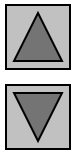
Outline

```
26
27    cout << "Face" << setw( 13 ) << "Frequency" << endl;
28
29    // output frequency elements 1-6 in tabular format
30    for ( int face = 1; face < arraySize; face++ )
31       cout << setw( 4 ) << face
32            << setw( 13 ) << frequency[ face ] << endl;
33
34    return 0;  // indicates successful termination
35
36 } // end main
```

```
Face    Frequency
   1         1003
   2         1004
   3          999
   4          980
   5         1013
   6         1001
```

fig04_10.cpp
(2 of 2)

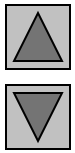
fig04_10.cpp
output (1 of 1)



Outline

fig04_11.cpp
(1 of 2)

```
1  // Fig. 4.11: fig04_11.cpp
2  // Student poll program.
3  #include <iostream>
4
5  using std::cout;
6  using std::endl;
7
8  #include <iomanip>
9
10 using std::setw;
11
12 int main()
13 {
14    // define array sizes
15    const int responseSize = 40;   // size of array responses
16    const int frequencySize = 11;  // size of array frequency
17
18    // place survey responses in array responses
19    int responses[ responseSize ] = { 1, 2, 6, 4, 8, 5, 9, 7, 8,
20        10, 1, 6, 3, 8, 6, 10, 3, 8, 2, 7, 6, 5, 7, 6, 8, 6, 7,
21        5, 6, 6, 5, 6, 7, 5, 6, 4, 8, 6, 8, 10 };
22
23    // initialize frequency counters to 0
24    int frequency[ frequencySize ] = { 0 };
25
```

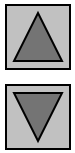


Outline

fig04_11.cpp
(2 of 2)

```
26    // for each answer, select value of an element of array
27    // responses and use that value as subscript in array
28    // frequency to determine element to increment
29    for ( int answer = 0; answer < responseSize; answer++ )
30       ++frequency[ responses[answer] ];
31
32    // display results
33    cout << "Rating" << setw( 17 ) <<
34
35    // output frequencies in tabular f
36    for ( int rating = 1; rating < frequencySize; rating++ )
37       cout << setw( 6 ) << rating
38            << setw( 17 ) << frequency[ rating ] << endl;
39
40    return 0;  // indicates successful termination
41
42 } // end main
```

`responses[answer]` is the rating (from 1 to 10). This determines the index in **`frequency[]`** to increment.



Outline

fig04_11.cpp
output (1 of 1)

```
Rating        Frequency
     1                2
     2                2
     3                2
     4                2
     5                5
     6               11
     7                5
     8                7
     9                1
    10                3
```

4.4 Examples Using Arrays

- Strings (more in ch. 5)
  - Arrays of characters
  - All strings end with **`null`** (**`'\0'`**)
  - Examples
    - **`char string1[] = "hello";`**
      - **`Null`** character implicitly added
      - **`string1`** has 6 elements
    - **`char string1[] = { 'h', 'e', 'l', 'l', 'o', '\0' };`**
  - Subscripting is the same

    `String1[ 0 ]` is **`'h'`**

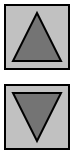
    `string1[ 2 ]` is **`'l'`**

4.4 Examples Using Arrays

- Input from keyboard

```
char string2[ 10 ];
cin >> string2;
```

  - Puts user input in string
    - Stops at first whitespace character
    - Adds **`null`** character
  - If too much text entered, data written beyond array
    - We want to avoid this (section 5.12 explains how)
- Printing strings
  - **`cout << string2 << endl;`**
    - Does not work for other array types
  - Characters printed until **`null`** found



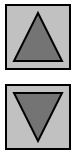
Outline

fig04_12.cpp
(1 of 2)

```
1  // Fig. 4_12: fig04_12.cpp
2  // Treating character arrays as strings.
3  #include <iostream>
4
5  using std::cout;
6  using std::cin;
7  using std::endl;
8
9  int main()
10 {
11    char string1[ 20 ],                  //
12    char string2[] = "string literal"; //
13
14    // read string from user into a
15    cout << "Enter the string \"hel
16    cin >> string1; // reads "hello" [space terminates input]
17
18    // output strings
19    cout << "string1 is: " << string1
20         << "\nstring2 is: " << string2;
21
22    cout << "\nstring1 with spaces between characters is:\n";
23
```

Two different ways to declare strings. **`string2`** is initialized, and its size determined automatically .

Examples of reading strings from the keyboard and printing them out.



Outline

```
24    // output characters until null character is reached
25    for ( int i = 0; string1[ i ] != '\0'; i++ )
26       cout << string1[ i ] << ' ';
27
28    cin >> string1;  // reads "there"
29    cout << "\nstring1 is: " << string1 << en
30
31    return 0;  // indicates successful termina
32
33 } // end main
```

Can access the characters in a string using array notation. The loop ends when the **`null`** character is found.

fig04_12.cpp (2 of 2)

fig04_12.cpp output (1 of 1)

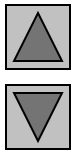
```
Enter the string "hello there": hello there
string1 is: hello
string2 is: string literal
string1 with spaces between characters is:
h e l l o
string1 is: there
```

4.4 Examples Using Arrays

- Recall static storage (chapter 3)
  - If **`static`**, local variables save values between function calls
  - Visible only in function body
  - Can declare local arrays to be static
    - Initialized to zero

```
static int array[3];
```

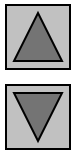
- If not static
  - Created (and destroyed) in every function call



Outline

fig04_13.cpp
(1 of 3)

```
1  // Fig. 4.13: fig04_13.cpp
2  // Static arrays are initialized to zero.
3  #include <iostream>
4
5  using std::cout;
6  using std::endl;
7
8  void staticArrayInit( void );      // function prototype
9  void automaticArrayInit( void );   // function prototype
10
11 int main()
12 {
13    cout << "First call to each function:\n";
14    staticArrayInit();
15    automaticArrayInit();
16
17    cout << "\n\nSecond call to each function:\n";
18    staticArrayInit();
19    automaticArrayInit();
20    cout << endl;
21
22    return 0;  // indicates successful termination
23
24 } // end main
25
```



Outline

fig04_13.cpp
(2 of 3)

```
26 // function to demonstrate a stati
27 void staticArrayInit( void )
28 {
29    // initializes elements to 0 first time function is called
30    static int array1[ 3 ];
31
32    cout << "\nValues on entering staticArrayInit:\n";
33
34    // output contents of array1
35    for ( int i = 0; i < 3; i++ )
36       cout << "array1[" << i << "] = " << array1[ i ] << "  ";
37
38    cout << "\nValues on exiting stati
39
40    // modify and output contents of array1
41    for ( int j = 0; j < 3; j++ )
42       cout << "array1[" << j << "] = "
43            << ( array1[ j ] += 5 ) << "  ";
44
45 } // end function staticArrayInit
46
```

Static array, initialized to zero on first function call.

Array data is changed; the modified values stay.

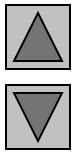
Outline

```
47 // function to demonstrate an automatic local array
48 void automaticArrayInit( void )
49 {
50    // initializes elements each time function is called
51    int array2[ 3 ] = { 1, 2, 3 };
52
53    cout << "\n\nValues on entering automaticArrayInit:\n";
54
55    // output contents of array2
56    for ( int i = 0; i < 3; i++ )
57       cout << "array2[" << i << "] = " << array2[ i ] << "  ";
58
59    cout << "\nValues on exiting automaticAr
60
61    // modify and output contents of array2
62    for ( int j = 0; j < 3; j++ )
63       cout << "array2[" << j << "] = "
64            << ( array2[ j ] += 5 ) << "  ";
65
66 } // end function automaticArrayInit
```

Automatic array, recreated with every function call.

Although the array is changed, it will be destroyed when the function exits and the changes will be lost.

fig04_13.cpp
(3 of 3)



Outline

fig04_13.cpp
output (1 of 1)

```
First call to each function:

Values on entering staticArrayInit:
array1[0] = 0  array1[1] = 0  array1[2] = 0
Values on exiting staticArrayInit:
array1[0] = 5  array1[1] = 5  array1[2] = 5

Values on entering automaticArrayInit:
array2[0] = 1  array2[1] = 2  array2[2] = 3
Values on exiting automaticArrayInit:
array2[0] = 6  array2[1] = 7  array2[2] = 8

Second call to each function:

Values on entering staticArrayInit:
array1[0] = 5  array1[1] = 5  array1[2] = 5
Values on exiting staticArrayInit:
array1[0] = 10  array1[1] = 10  array1[2] = 10

Values on entering automaticArrayInit:
array2[0] = 1  array2[1] = 2  array2[2] = 3
Values on exiting automaticArrayInit:
array2[0] = 6  array2[1] = 7  array2[2] = 8
```

4.5 Passing Arrays to Functions

- Specify name without brackets
  - To pass array **myArray** to **myFunction**

```
int myArray[ 24 ];
myFunction( myArray, 24 );
```

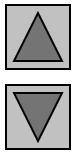
  - Array size usually passed, but not required
    - Useful to iterate over all elements

4.5 Passing Arrays to Functions

- Arrays passed-by-reference
  - Functions can modify original array data
  - Value of name of array is address of first element
    - Function knows where the array is stored
    - Can change original memory locations
- Individual array elements passed-by-value
  - Like regular variables
  - **`square( myArray[3] );`**

4.5 Passing Arrays to Functions

- Functions taking arrays
  - Function prototype
    - **`void modifyArray( int b[], int arraySize );`**
    - **`void modifyArray( int [], int );`**
      - Names optional in prototype
    - Both take an integer array and a single integer
  - No need for array size between brackets
    - Ignored by compiler
  - If declare array parameter as **`const`**
    - Cannot be modified (compiler error)
    - **`void doNotModify( const int [] );`**

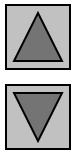


Outline

fig04_14.cpp
(1 of 3)

```
1  // Fig. 4.14: fig04_14.cpp
2  // Passing arrays and individual array elements to functions.
3  #include <iostream>
4
5  using std::cout;
6  using std::endl;
7
8  #include <iomanip>
9
10 using std::setw;
11
12 void modifyArray( int [], int );  // appears strange
13 void modifyElement( int );
14
15 int main()
16 {
17    const int arraySize = 5;                 // size of array a
18    int a[ arraySize ] = { 0, 1, 2, 3, 4 };  // initialize a
19
20    cout << "Effects of passing entire array by reference:"
21         << "\n\nThe values of the original array are:\n";
22
23    // output original array
24    for ( int i = 0; i < arraySize; i++ )
25       cout << setw( 3 ) << a[ i ];
```

Syntax for accepting an array in parameter list.



Outline

fig04_14.cpp
(2 of 3)

```
26
27    cout << endl;
28
29    // pass array a to modifyArray
30    modifyArray( a, arraySize );
31
32    cout << "The values of the modified array are:\n";
33
34    // output modified array
35    for ( int j = 0; j < arraySize; j++ )
36       cout << setw( 3 ) << a[ j ];
37
38    // output value of a[ 3 ]
39    cout << "\n\n\n"
40         << "Effects of passing array e
41         << "\n\nThe value of a[3] is "
42
43    // pass array element a[ 3 ] by val
44    modifyElement( a[ 3 ] );
45
46    // output value of a[ 3 ]
47    cout << "The value of a[3] is " << a[ 3 ] << endl;
48
49    return 0;  // indicates successful termination
50
51 } // end main
```

Pass array name (**a**) and size to function. Arrays are passed-by-reference.

Pass a single array element by value; the original cannot be modified.

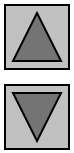
Outline

fig04_14.cpp
(3 of 3)

```
52
53 // in function modifyArray, "b" points to
54 // the original array "a" in memory
55 void modifyArray( int b[], int sizeOfArray )
56 {
57    // multiply each array element by 2
58    for ( int k = 0; k < sizeOfArray; k++ )
59       b[ k ] *= 2;
60
61 } // end function modifyArray
62
63 // in function modifyElement, "e" is a lo
64 // array element a[ 3 ] passed from main
65 void modifyElement( int e )
66 {
67    // multiply parameter by 2
68    cout << "Value in modifyElement is "
69         << ( e *= 2 ) << endl;
70
71 } // end function modifyElement
```

Although named **b**, the array points to the original array **a**. It can modify **a**'s data.

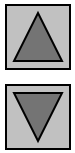
Individual array elements are passed by value, and the originals cannot be changed.



Outline

fig04_14.cpp
output (1 of 1)

```
Effects of passing entire array by reference:

The values of the original array are:
  0  1  2  3  4
The values of the modified array are:
  0  2  4  6  8


Effects of passing array element by value:

The value of a[3] is 6
Value in modifyElement is 12
The value of a[3] is 6
```

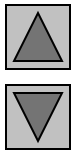


Outline

fig04_15.cpp (1 of 2)

```
1  // Fig. 4.15: fig04_15.cpp
2  // Demonstrating the const type qualifier.
3  #include <iostream>
4
5  using std::cout;
6  using std::endl;
7
8  void tryToModifyArray( const int [] );  //
9
10 int main()
11 {
12    int a[] = { 10, 20, 30 };
13
14    tryToModifyArray( a );
15
16    cout << a[ 0 ] << ' ' << a[ 1 ] << ' ' << a[ 2 ] << '\n';
17
18    return 0;  // indicates successful termination
19
20 } // end main
21
```

Array parameter declared as **`const`**. Array cannot be modified, even though it is passed by reference.



Outline

fig04_15.cpp (2 of 2)

```
22 // In function tryToModifyArray, "b" cannot be used
23 // to modify the original array "a" in main.
24 void tryToModifyArray( const int b[] )
25 {
26    b[ 0 ] /= 2;    // error
27    b[ 1 ] /= 2;    // error
28    b[ 2 ] /= 2;    // error
29
30 } // end function tryToModifyArray
```

fig04_15.cpp output (1 of 1)

```
d:\cpphtp4_examples\ch04\Fig04_15.cpp(26) : error C2166:
   l-value specifies const object
d:\cpphtp4_examples\ch04\Fig04_15.cpp(27) : error C2166:
   l-value specifies const object
d:\cpphtp4_examples\ch04\Fig04_15.cpp(28) : error C2166:
   l-value specifies const object
```

4.6 Sorting Arrays

- Sorting data
  - Important computing application
  - Virtually every organization must sort some data
    - Massive amounts must be sorted
- Bubble sort (sinking sort)
  - Several passes through the array
  - Successive pairs of elements are compared
    - If increasing order (or identical), no change
    - If decreasing order, elements exchanged
  - Repeat these steps for every element

4.6 Sorting Arrays

- Example:
  - Go left to right, and exchange elements as necessary
    - One pass for each element
  - Original: 3 4 2 7 6
  - Pass 1: 3 2 4 6 7 (elements exchanged)
  - Pass 2: 2 3 4 6 7
  - Pass 3: 2 3 4 6 7 (no changes needed)
  - Pass 4: 2 3 4 6 7
  - Pass 5: 2 3 4 6 7
  - Small elements "bubble" to the top (like 2 in this example)

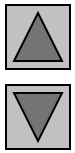
4.6 Sorting Arrays

- Swapping variables

```
int x = 3, y = 4;
y = x;
x = y;
```

- What happened?
  - Both x and y are 3!
  - Need a temporary variable
- Solution

```
int x = 3, y = 4, temp = 0;
temp = x;  // temp gets 3
x = y;     // x gets 4
y = temp;  // y gets 3
```

Outline

fig04_16.cpp
(1 of 3)

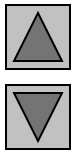
```
1  // Fig. 4.16: fig04_16.cpp
2  // This program sorts an array's values into ascending order.
3  #include <iostream>
4
5  using std::cout;
6  using std::endl;
7
8  #include <iomanip>
9
10 using std::setw;
11
12 int main()
13 {
14    const int arraySize = 10;  // size of array a
15    int a[ arraySize ] = { 2, 6, 4, 8, 10, 12, 89, 68, 45, 37 };
16    int hold;  // temporary location used to swap array elements
17
18    cout << "Data items in original order\n";
19
20    // output original array
21    for ( int i = 0; i < arraySize; i++ )
22       cout << setw( 4 ) << a[ i ];
23
```

```
24    // bubble sort
25    // loop to control number of passes
26    for ( int pass = 0; pass < arraySize - 1; pass++ )
27
28       // loop to control number of comparisons per pass
29       for ( int j = 0; j < arraySize - 1; j++ )
30
31          // compare side-by-side elements and swap t
32          // first element is greater than second ele
33          if ( a[ j ] > a[ j + 1 ] ) {
34             hold = a[ j ];
35             a[ j ] = a[ j + 1 ];
36             a[ j + 1 ] = hold;
37
38          } // end if
39
```

Do a pass for each element in the array.

If the element on the left (index **j**) is larger than the element on the right (index **j + 1**), then we swap them. Remember the need of a temp variable.

fig04_16.cpp (2 of 3)



Outline

```
40    cout << "\nData items in ascending order\n";
41
42    // output sorted array
43    for ( int k = 0; k < arraySize; k++ )
44       cout << setw( 4 ) << a[ k ];
45
46    cout << endl;
47
48    return 0;  // indicates successful termination
49
50 } // end main
```

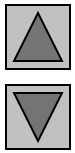
```
Data items in original order
   2   6   4   8  10  12  89  68  45  37
Data items in ascending order
   2   4   6   8  10  12  37  45  68  89
```

fig04_16.cpp (3 of 3)

fig04_16.cpp output (1 of 1)

4.7 Case Study: Computing Mean, Median and Mode Using Arrays

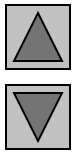
- Mean
  - Average (sum/number of elements)
- Median
  - Number in middle of sorted list
  - 1, 2, 3, 4, 5 (3 is median)
  - If even number of elements, take average of middle two
- Mode
  - Number that occurs most often
  - 1, 1, 1, 2, 3, 3, 4, 5 (1 is mode)



Outline

fig04_17.cpp
(1 of 8)

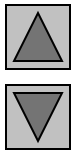
```
1  // Fig. 4.17: fig04_17.cpp
2  // This program introduces the topic of survey data analysis.
3  // It computes the mean, median, and mode of the data.
4  #include <iostream>
5
6  using std::cout;
7  using std::endl;
8  using std::fixed;
9  using std::showpoint;
10
11 #include <iomanip>
12
13 using std::setw;
14 using std::setprecision;
15
16 void mean( const int [], int );
17 void median( int [], int );
18 void mode( int [], int [], int );
19 void bubbleSort( int[], int );
20 void printArray( const int[], int );
21
22 int main()
23 {
24    const int responseSize = 99;  // size of array responses
25
```



Outline

fig04_17.cpp
(2 of 8)

```
26    int frequency[ 10 ] = { 0 };  // initialize array frequency
27
28    // initialize array responses
29    int response[ responseSize ] =
30          { 6, 7, 8, 9, 8, 7, 8, 9, 8, 9,
31            7, 8, 9, 5, 9, 8, 7, 8, 7, 8,
32            6, 7, 8, 9, 3, 9, 8, 7, 8, 7,
33            7, 8, 9, 8, 9, 8, 9, 7, 8, 9,
34            6, 7, 8, 7, 8, 7, 9, 8, 9, 2,
35            7, 8, 9, 8, 9, 8, 9, 7, 5, 3,
36            5, 6, 7, 2, 5, 3, 9, 4, 6, 4,
37            7, 8, 9, 6, 8, 7, 8, 9, 7, 8,
38            7, 4, 4, 2, 5, 3, 8, 7, 5, 6,
39            4, 5, 6, 1, 6, 5, 7, 8, 7 };
40
41    // process responses
42    mean( response, responseSize );
43    median( response, responseSize );
44    mode( frequency, response, responseSize );
45
46    return 0;  // indicates successful termination
47
48 } // end main
49
```

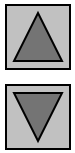


Outline

fig04_17.cpp
(3 of 8)

```
50 // calculate average of all response values
51 void mean( const int answer[], int arraySize )
52 {
53    int total = 0;
54
55    cout << "********\n  Mean\n********\n";
56
57    // total response values
58    for ( int i = 0; i < arraySize; i++ )
59       total += answer[ i ];
60
61    // format and output results
62    cout << fixed << setprecision( 4 );
63
64    cout << "The mean is the average value of the data\n"
65         << "items. The mean is equal to the total of\n"
66         << "all the data items divided by the numb
67         << "of data items (" << arraySize
68         << "). The mean value for\nthis run is: "
69         << total << " / " << arraySize << " = "
70         << static_cast< double >( total ) / arraySize
71         << "\n\n";
72
73 } // end function mean
74
```

We cast to a double to get decimal points for the average (instead of an integer).

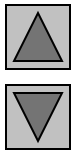


Outline

fig04_17.cpp (4 of 8)

```
75 // sort array and determine median element's value
76 void median( int answer[], int size )
77 {
78    cout << "\n********\n Median\n********\n"
79         << "The unsorted array of
80
81    printArray( answer, size );  //
82
83    bubbleSort( answer, size );  // sort array
84
85    cout << "\n\nThe sorted array is";
86    printArray( answer, size );  // output sorted array
87
88    // display median element
89    cout << "\n\nThe median is element " << size / 2
90         << " of\nthe sorted " << size
91         << " element array.\nFor this run the median is "
92         << answer[ size / 2 ] << "\n\n";
93
94 } // end function median
95
```

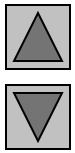
Sort array by passing it to a function. This keeps the program modular.



Outline

fig04_17.cpp
(5 of 8)

```
96 // determine most frequent response
97 void mode( int freq[], int answer[], int size )
98 {
99    int largest = 0;    // represents largest frequency
100   int modeValue = 0;  // represents most frequent response
101
102   cout << "\n********\n  Mode\n********\n";
103
104   // initialize frequencies to 0
105   for ( int i = 1; i <= 9; i++ )
106      freq[ i ] = 0;
107
108   // summarize frequencies
109   for ( int j = 0; j < size; j++ )
110      ++freq[ answer[ j ] ];
111
112   // output headers for result columns
113   cout << "Response" << setw( 11 ) << "Frequency"
114        << setw( 19 ) << "Histogram\n\n" << setw( 55 )
115        << "1    1    2    2\n" << setw( 56 )
116        << "5    0    5    0    5\n\n";
117
```

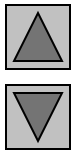


Outline

fig04_17.cpp
(6 of 8)

```
118    // output results
119    for ( int rating = 1; rating <= 9; rating++ ) {
120       cout << setw( 8 ) << rating << setw( 11 )
121            << freq[ rating ] << "
122
123       // keep track of mode value and
124       if ( freq[ rating ] > largest ) {
125          largest = freq[ rating ];
126          modeValue = rating;
127
128       } // end if
129
130       // output histogram bar representing frequency value
131       for ( int k = 1; k <= freq[ rating ]; k++ )
132          cout << '*';
133
134       cout << '\n';  // begin new line of output
135
136    } // end outer for
137
138    // display the mode value
139    cout << "The mode is the most frequent value.\n"
140         << "For this run the mode is " << modeValue
141         << " which occurred " << largest << " times." << endl;
142
143 } // end function mode
```

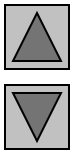
The mode is the value that occurs most often (has the highest value in **`freq`**).



Outline

fig04_17.cpp
(7 of 8)

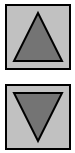
```
144
145 // function that sorts an array with bubble sort algorithm
146 void bubbleSort( int a[], int size )
147 {
148    int hold;  // temporary location used to swap elements
149
150    // loop to control number of passes
151    for ( int pass = 1; pass < size; pass++ )
152
153       // loop to control number of comparisons per pass
154       for ( int j = 0; j < size - 1; j++ )
155
156          // swap elements if out of order
157          if ( a[ j ] > a[ j + 1 ] ) {
158             hold = a[ j ];
159             a[ j ] = a[ j + 1 ];
160             a[ j + 1 ] = hold;
161
162          } // end if
163
164 } // end function bubbleSort
165
```



Outline

```
166 // output array contents (20 values per row)
167 void printArray( const int a[], int size )
168 {
169    for ( int i = 0; i < size; i++ ) {
170
171       if ( i % 20 == 0 )  // begin new line every 20 values
172          cout << endl;
173
174       cout << setw( 2 ) << a[ i ];
175
176    } // end for
177
178 } // end function printArray
```

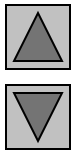
fig04_17.cpp
(8 of 8)



Outline

fig04_17.cpp output (1 of 2)

```
********
  Mean
********
The mean is the average value of the data
items. The mean is equal to the total of
all the data items divided by the number
of data items (99). The mean value for
this run is: 681 / 99 = 6.8788
********
 Median
********
The unsorted array of responses is
 6 7 8 9 8 7 8 9 8 9 7 8 9 5 9 8 7 8 7 8
 6 7 8 9 3 9 8 7 8 7 7 8 9 8 9 8 9 7 8 9
 6 7 8 7 8 7 9 8 9 2 7 8 9 8 9 8 9 7 5 3
 5 6 7 2 5 3 9 4 6 4 7 8 9 6 8 7 8 9 7 8
 7 4 4 2 5 3 8 7 5 6 4 5 6 1 6 5 7 8 7

The sorted array is
 1 2 2 2 3 3 3 3 4 4 4 4 4 5 5 5 5 5 5 5
 5 6 6 6 6 6 6 6 6 6 7 7 7 7 7 7 7 7 7 7
 7 7 7 7 7 7 7 7 7 7 7 7 7 8 8 8 8 8 8 8
 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9

The median is element 49 of
the sorted 99 element array.
For this run the median is 7
```



Outline

fig04_17.cpp output (2 of 2)

```
********
  Mode
********
Response   Frequency        Histogram

                                  1    1    2    2
                             5    0    5    0    5

       1           1          *
       2           3          ***
       3           4          ****
       4           5          *****
       5           8          ********
       6           9          *********
       7          23          ***********************
       8          27          ***************************
       9          19          *******************

The mode is the most frequent value.
For this run the mode is 8 which occurred 27 times.
```

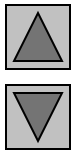
4.8 Searching Arrays: Linear Search and Binary Search

- Search array for a key value
- Linear search
  - Compare each element of array with key value
    - Start at one end, go to other
  - Useful for small and unsorted arrays
    - Inefficient
    - If search key not present, examines every element

4.8 Searching Arrays: Linear Search and Binary Search

- Binary search
  - Only used with sorted arrays
  - Compare middle element with key
    - If equal, match found
    - If key < middle
      - Repeat search on first half of array
    - If key > middle
      - Repeat search on last half
  - Very fast
    - At most N steps, where 2^N > # of elements
    - 30 element array takes at most 5 steps

      2^5 > 30

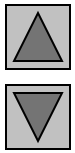


Outline

fig04_19.cpp (1 of 2)

```
1  // Fig. 4.19: fig04_19.cpp
2  // Linear search of an array.
3  #include <iostream>
4
5  using std::cout;
6  using std::cin;
7  using std::endl;
8
9  int linearSearch( const int [], int, int );  // prototype
10
11 int main()
12 {
13    const int arraySize = 100;  // size of array a
14    int a[ arraySize ];         // create array a
15    int searchKey;              // value to locate in a
16
17    for ( int i = 0; i < arraySize; i++ )  // create some data
18       a[ i ] = 2 * i;
19
20    cout << "Enter integer search key: ";
21    cin >> searchKey;
22
23    // attempt to locate searchKey in array a
24    int element = linearSearch( a, searchKey, arraySize );
25
```

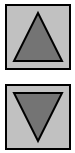
Takes array, search key, and array size.



Outline

fig04_19.cpp
(2 of 2)

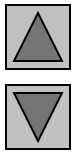
```
26    // display results
27    if ( element != -1 )
28       cout << "Found value in element " << element << endl;
29    else
30       cout << "Value not found" << endl;
31
32    return 0;  // indicates successful termination
33
34 } // end main
35
36 // compare key to every element of array until location is
37 // found or until end of array is reached; return subscript of
38 // element if key or -1 if key not found
39 int linearSearch( const int array[], int key, int sizeOfArray )
40 {
41    for ( int j = 0; j < sizeOfArray; j++ )
42
43       if ( array[ j ] == key )  // if found,
44          return j;              // return location of key
45
46    return -1;  // key not found
47
48 } // end function linearSearch
```



Outline

```
Enter integer search key: 36
Found value in element 18

Enter integer search key: 37
Value not found
```

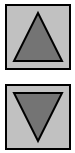
fig04_19.cpp
output (1 of 1)



Outline

fig04_20.cpp
(1 of 6)

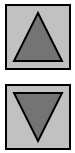
```
1  // Fig. 4.20: fig04_20.cpp
2  // Binary search of an array.
3  #include <iostream>
4
5  using std::cout;
6  using std::cin;
7  using std::endl;
8
9  #include <iomanip>
10
11 using std::setw;
12
13 // function prototypes
14 int binarySearch( const int [], int, int, int, int );
15 void printHeader( int );
16 void printRow( const int [], int, int, int, int );
17
18 int main()
19 {
20    const int arraySize = 15;  // size of array a
21    int a[ arraySize ];        // create array a
22    int key;                   // value to locate in a
23
24    for ( int i = 0; i < arraySize; i++ )  // create some data
25       a[ i ] = 2 * i;
26
```



Outline

fig04_20.cpp
(2 of 6)

```
27    cout << "Enter a number between 0 and 28: ";
28    cin >> key;
29
30    printHeader( arraySize );
31
32    // search for key in array a
33    int result =
34       binarySearch( a, key, 0, arraySize - 1, arraySize );
35
36    // display results
37    if ( result != -1 )
38       cout << '\n' << key << " found in array element "
39            << result << endl;
40    else
41       cout << '\n' << key << " not found" << endl;
42
43    return 0;  // indicates successful termination
44
45 } // end main
46
```

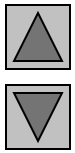


Outline

fig04_20.cpp
(3 of 6)

```
47 // function to perform binary search of an array
48 int binarySearch( const int b[], int searchKey, int low,
49    int high, int size )
50 {
51    int middle;
52
53    // loop until low subscript is gre
54    while ( low <= high ) {
55
56       // determine middle element of subarray being searched
57       middle = ( low + high ) / 2;
58
59       // display subarray used in this loop iteration
60       printRow( b, low, middle, high, size );
61
```

Determine middle element



Outline

fig04_20.cpp
(4 of 6)

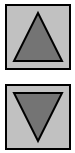
```
62       // if searchKey matches middle element, return middle
63       if ( searchKey == b[ middle ] )  // match
64          return middle;
65
66       else
67
68          // if searchKey less than middle e
69          // set new high element
70          if ( searchKey < b[ middle ] )
71             high = middle - 1;  // search low end of array
72
73          // if searchKey greater than middl
74          // set new low element
75          else
76             low = middle + 1;   // search h
77    }
78
79    return -1;  // searchKey not found
80
81 } // end function binarySearch
```

Use the rule of binary search:
If key equals middle, match

If less, search low end

If greater, search high end

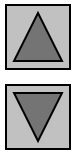
Loop sets low, middle and high dynamically. If searching the high end, the new low is the element above the middle.



Outline

fig04_20.cpp
(5 of 6)

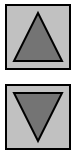
```
82
83 // print header for output
84 void printHeader( int size )
85 {
86    cout << "\nSubscripts:\n";
87
88    // output column heads
89    for ( int j = 0; j < size; j++ )
90       cout << setw( 3 ) << j << ' ';
91
92    cout << '\n';  // start new line of output
93
94    // output line of - characters
95    for ( int k = 1; k <= 4 * size; k++ )
96       cout << '-';
97
98    cout << endl;  // start new line of output
99
100 } // end function printHeader
101
```



Outline

fig04_20.cpp
(6 of 6)

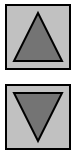
```
102 // print one row of output showing the current
103 // part of the array being processed
104 void printRow( const int b[], int low, int mid,
105    int high, int size )
106 {
107    // loop through entire array
108    for ( int m = 0; m < size; m++ )
109
110       // display spaces if outside current subarray range
111       if ( m < low || m > high )
112          cout << "    ";
113
114       // display middle element marked with a *
115       else
116
117          if ( m == mid )           // mark middle value
118             cout << setw( 3 ) << b[ m ] << '*';
119
120          // display other elements in subarray
121          else
122             cout << setw( 3 ) << b[ m ] << ' ';
123
124    cout << endl;  // start new line of output
125
126 } // end function printRow
```



Outline

fig04_20.cpp
output (1 of 2)

```
Enter a number between 0 and 28: 6

Subscripts:
  0   1   2   3   4   5   6   7   8   9  10  11  12  13  14
-------------------------------------------------------------
  0   2   4   6   8  10  12  14* 16  18  20  22  24  26  28
  0   2   4   6*  8  10  12

6 found in array element 3



Enter a number between 0 and 28: 25

Subscripts:
  0   1   2   3   4   5   6   7   8   9  10  11  12  13  14
-------------------------------------------------------------
  0   2   4   6   8  10  12  14* 16  18  20  22  24  26  28
                              16  18  20  22* 24  26  28
                                          24  26* 28
                                          24*

25 not found
```



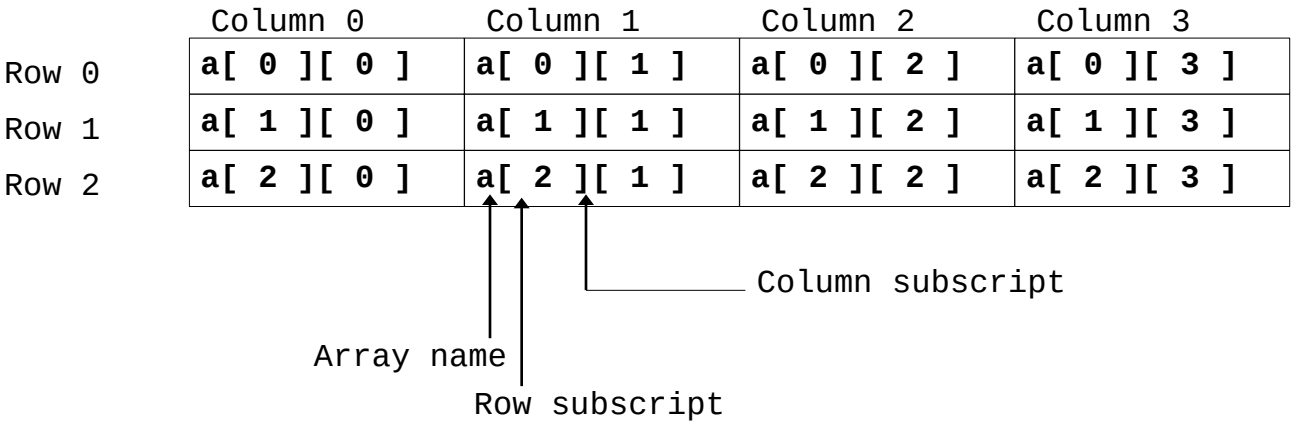
Outline

fig04_20.cpp
output (2 of 2)

```
Enter a number between 0 and 28: 8

Subscripts:
  0   1   2   3   4   5   6   7   8   9  10  11  12  13  14
---------------------------------------------------------------
  0   2   4   6   8  10  12  14* 16  18  20  22  24  26  28
  0   2   4   6*  8  10  12
                 8  10* 12
                 8*

8 found in array element 4
```

4.9 Multiple-Subscripted Arrays

- Multiple subscripts
  - **a[i][j]**
  - Tables with rows and columns
  - Specify row, then column
  - "Array of arrays"
    - **a[0]** is an array of 4 elements
    - **a[0][0]** is the first element of that array



4.9 Multiple-Subscripted Arrays

- To initialize
  - Default of **0**
  - Initializers grouped by row in braces

```
int b[ 2 ][ 2 ] = { { 1, 2 }, { 3, 4 } };
                    Row 0      Row 1
```

1	2
3	4

```
int b[ 2 ][ 2 ] = { { 1 }, { 3, 4 } };
```

1	0
3	4

4.9 Multiple-Subscripted Arrays

- Referenced like normal

```
cout << b[ 0 ][ 1 ];
```

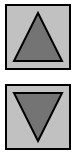
1	0
3	4

  - Outputs **0**
  - Cannot reference using commas

```
cout << b[ 0, 1 ];
```

    - Syntax error

- Function prototypes
  - Must specify sizes of subscripts
    - First subscript not necessary, as with single-scripted arrays
  - **void printArray(int [][3]);**



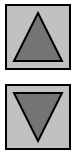
Outline

fig04_22.cpp (1 of 2)

```
1  // Fig. 4.22: fig04_22.cpp
2  // Initializing multidimensional arrays.
3  #include <iostream>
4
5  using std::cout;
6  using std::endl;
7
8  void printArray( int [][ 3 ] );
9
10 int main()
11 {
12    int array1[ 2 ][ 3 ] = { { 1, 2, 3 }, { 4, 5, 6 } };
13    int array2[ 2 ][ 3 ] = { 1, 2, 3, 4, 5 };
14    int array3[ 2 ][ 3 ] = { { 1, 2 }, { 4 } };
15
16    cout << "Values in array1 by row are:" << endl;
17    printArray( array1 );
18
19    cout << "Values in array2 by row are:" << endl;
20    printArray( array2 );
21
22    cout << "Values in array3 by row are:" << endl;
23    printArray( array3 );
24
25    return 0;  // indicates successful termination
26
27 } // end main
```

Note the format of the prototype.

Note the various initialization styles. The elements in **`array2`** are assigned to the first row and then the second.



Outline

```
28
29 // function to output array with two rows
30 void printArray( int a[][ 3 ] )
31 {
32    for ( int i = 0; i < 2; i++ ) {    // f
33
34       for ( int j = 0; j < 3; j++ )   // output column values
35          cout << a[ i ][ j ] << ' ';
36
37       cout << endl;  // start new line of output
38
39    } // end outer for structure
40
41 } // end function printArray
```

For loops are often used to iterate through arrays. Nested loops are helpful with multiple-subscripted arrays.

fig04_22.cpp (2 of 2)

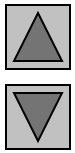
fig04_22.cpp output (1 of 1)

```
Values in array1 by row are:
1 2 3
4 5 6
Values in array2 by row are:
1 2 3
4 5 0
Values in array3 by row are:
1 2 0
4 0 0
```

4.9 Multiple-Subscripted Arrays

- Next: program showing initialization
  - After, program to keep track of students grades
  - Multiple-subscripted array (table)
  - Rows are students
  - Columns are grades

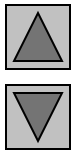
	Quiz1	Quiz2
Student0	95	85
Student1	89	80



Outline

fig04_23.cpp
(1 of 6)

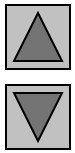
```
1  // Fig. 4.23: fig04_23.cpp
2  // Double-subscripted array example.
3  #include <iostream>
4
5  using std::cout;
6  using std::endl;
7  using std::fixed;
8  using std::left;
9
10 #include <iomanip>
11
12 using std::setw;
13 using std::setprecision;
14
15 const int students = 3;   // number of students
16 const int exams = 4;      // number of exams
17
18 // function prototypes
19 int minimum( int [][ exams ], int, int );
20 int maximum( int [][ exams ], int, int );
21 double average( int [], int );
22 void printArray( int [][ exams ], int, int );
23
```



Outline

fig04_23.cpp
(2 of 6)

```
24 int main()
25 {
26    // initialize student grades for three students (rows)
27    int studentGrades[ students ][ exams ] =
28       { { 77, 68, 86, 73 },
29         { 96, 87, 89, 78 },
30         { 70, 90, 86, 81 } };
31
32    // output array studentGrades
33    cout << "The array is:\n";
34    printArray( studentGrades, students, exams );
35
36    // determine smallest and largest grade values
37    cout << "\n\nLowest grade: "
38         << minimum( studentGrades, students, exams )
39         << "\nHighest grade: "
40         << maximum( studentGrades, students, exams ) << '\n';
41
42    cout << fixed << setprecision( 2 );
43
```

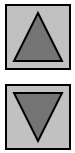


Outline

fig04_23.cpp (3 of 6)

```
44    // calculate average grade for each student
45    for ( int person = 0; person < students; person++ )
46       cout << "The average grade for student " << person
47            << " is "
48            << average( studentGrades[ person ], exams )
49            << endl;
50
51    return 0;  // indicates successful termi
52
53 } // end main
54
55 // find minimum grade
56 int minimum( int grades[][ exams ], int pupi
57 {
58    int lowGrade = 100; // initialize to highest possible grade
59
60    for ( int i = 0; i < pupils; i++ )
61
62       for ( int j = 0; j < tests; j++ )
63
64          if ( grades[ i ][ j ] < lowGrade )
65             lowGrade = grades[ i ][ j ];
66
67    return lowGrade;
68
69 } // end function minimum
```

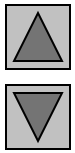
Determines the average for one student. We pass the array/row containing the student's grades. Note that **`studentGrades[0]`** is itself an array.



Outline

fig04_23.cpp
(4 of 6)

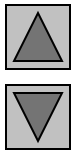
```
70
71 // find maximum grade
72 int maximum( int grades[][ exams ], int pupils, int tests )
73 {
74    int highGrade = 0;  // initialize to lowest possible grade
75
76    for ( int i = 0; i < pupils; i++ )
77
78       for ( int j = 0; j < tests; j++ )
79
80          if ( grades[ i ][ j ] > highGrade )
81             highGrade = grades[ i ][ j ];
82
83    return highGrade;
84
85 } // end function maximum
86
```



Outline

fig04_23.cpp
(5 of 6)

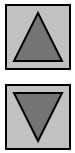
```
87 // determine average grade for particular student
88 double average( int setOfGrades[], int tests )
89 {
90    int total = 0;
91
92    // total all grades for one student
93    for ( int i = 0; i < tests; i++ )
94       total += setOfGrades[ i ];
95
96    return static_cast< double >( total ) / tests;  // average
97
98 } // end function maximum
```



Outline

```
99
100 // Print the array
101 void printArray( int grades[][ exams ], int pupils, int tests )
102 {
103    // set left justification and output column heads
104    cout << left << "               [0]  [1]  [2]  [3]";
105
106    // output grades in tabular format
107    for ( int i = 0; i < pupils; i++ ) {
108
109       // output label for row
110       cout << "\nstudentGrades[" << i << "] ";
111
112       // output one grades for one student
113       for ( int j = 0; j < tests; j++ )
114          cout << setw( 5 ) << grades[ i ][ j ];
115
116    } // end outer for
117
118 } // end function printArray
```

fig04_23.cpp
(6 of 6)



Outline

fig04_23.cpp
output (1 of 1)

```
The array is:
                 [0]  [1]  [2]  [3]
studentGrades[0] 77   68   86   73
studentGrades[1] 96   87   89   78
studentGrades[2] 70   90   86   81

Lowest grade: 68
Highest grade: 96
The average grade for student 0 is 76.00
The average grade for student 1 is 87.50
The average grade for student 2 is 81.75
```