6

C Arrays

Now go, write it before them in a table,
and note it in a book.

—Isaiah 30:8

To go beyond is as wrong as to fall short.

—Confucius

Begin at the beginning, …
and go on till you come to the end: then stop.

—Lewis Carroll

OBJECTIVES

In this chapter you will learn:

- To use the array data structure to represent lists and tables of values.
- To define an array, initialize an array and refer to individual elements of an array.
- To define symbolic constants.
- To pass arrays to functions.
- To use arrays to store, sort and search lists and tables of values.
- To define and manipulate multiple-subscripted arrays.

Outline

6.1 Introduction

- **Arrays**
  - **Structures of related data items**
  - **Static entity – same size throughout program**
  - **Dynamic data structures discussed in Chapter 12**

6.2 Arrays

- **Array**
  - **Group of consecutive memory locations**
  - **Same name and type**
- **To refer to an element, specify**
  - **Array name**
  - **Position number**
- **Format:**

  arrayname`[` *position number* `]`
  - **First element at position `0`**
  - **`n` element array named `c`:**
    - `c[ 0 ], c[ 1 ]...c[ n - 1 ]`

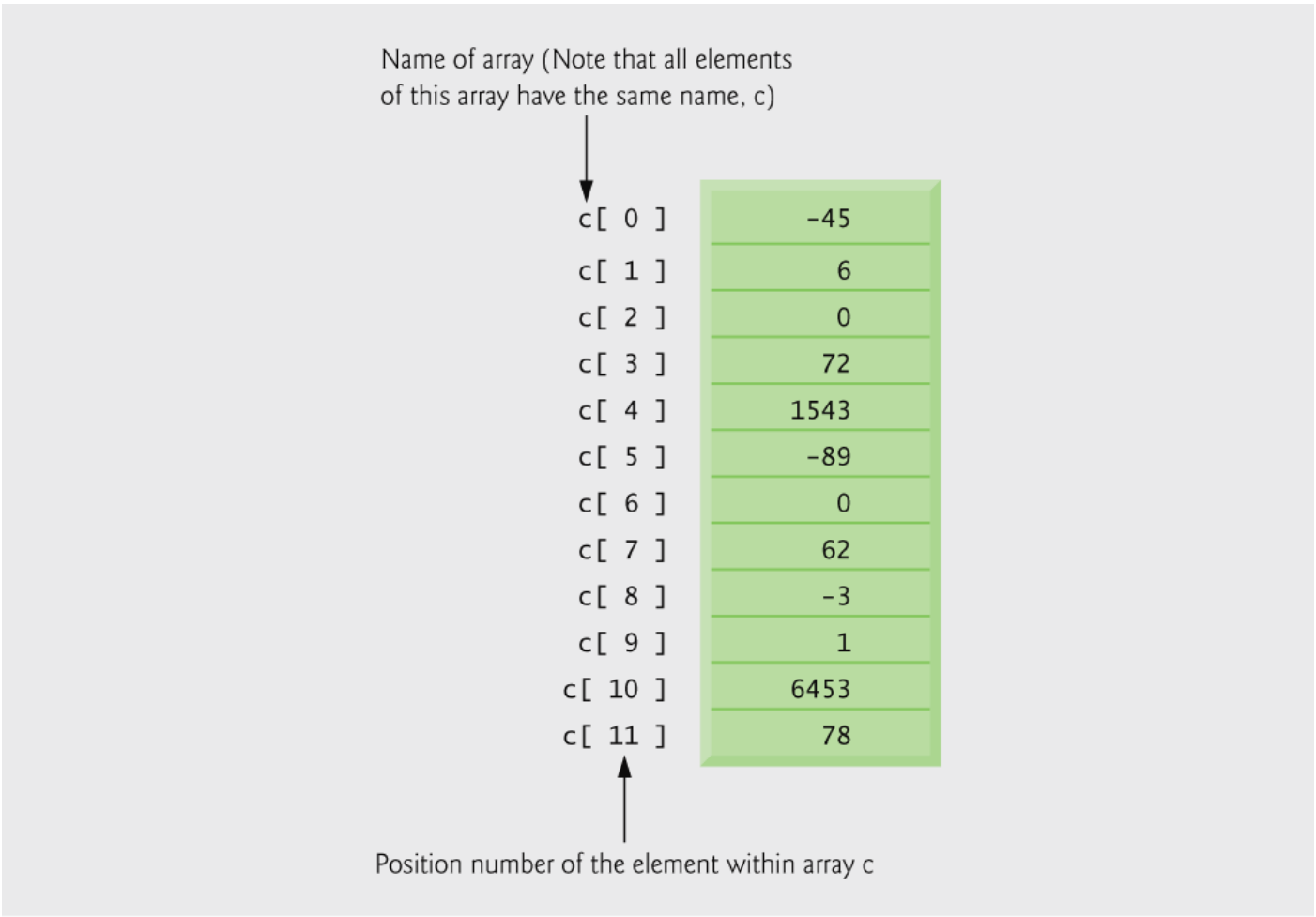

Fig. 6.1 | 12-element array.

6.2 Arrays

- **Array elements are like normal variables**

```
c[ 0 ] =  3;
printf( "%d", c[ 0 ] );
```

  - **Perform operations in subscript. If `x` equals 3**

```
c[ 5 - 2 ] == c[ 3 ] == c[ x ]
```

Common Programming Error 6.1

It is important to note the difference between the "seventh element of the array" and "array element seven." Because array subscripts begin at 0, the "seventh element of the array" has a subscript of 6, while "array element seven" has a subscript of 7 and is actually the eighth element of the array. This is a source of "off-by-one" errors.

Operators	Associativity	Type
`[]` `()`	left to right	highest
`++` `--` `!` (*type*)	right to left	unary
`*` `/` `%`	left to right	multiplicative
`+` `-`	left to right	additive
`<` `<=` `>` `>=`	left to right	relational
`==` `!=`	left to right	equality
`&&`	left to right	logical AND
`||`	left to right	logical OR
`?:`	right to left	conditional
`=` `+=` `-=` `*=` `/=` `%=`	right to left	assignment
`,`	left to right	comma

Fig. 6.2 | Operator precedence.

6.3 Defining Arrays

- **When defining arrays, specify**
  - **Name**
  - **Type of array**
  - **Number of elements**

    ```
    arrayType arrayName[ numberOfElements ];
    ```
  - **Examples:**

    ```
    int c[ 10 ];
    float myArray[ 3284 ];
    ```
- **Defining multiple arrays of same type**
  - **Format similar to regular variables**
  - **Example:**

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

6.4 Array Examples

- **Initializers**

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

  - **If not enough initializers, rightmost elements become 0**

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

    - **All elements 0**
  - **If too many initializers, a syntax error occurs**
  - **C arrays have no bounds checking**
- **If size omitted, initializers determine it**

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

  - **5 initializers, therefore 5 element array**

Outline

fig06_03.c

(1 of 2)

```
1  /* Fig. 6.3: fig06_03.c
2     initializing an array */
3  #include <stdio.h>
4
5  /* function main begins program execution */
6  int main( void )
7  {
8     int n[ 10 ]; /* n is an array of 10 integers */
9     int i; /* counter */
10
11    /* initialize elements of array n to 0 */
12    for ( i = 0; i < 10; i++ ) {
13       n[ i ] = 0; /* set element at location i to 0 */
14    } /* end for */
15
16    printf( "%s%13s\n", "Element", "Value" );
17
18    /* output contents of array n in tabular format */
19    for ( i = 0; i < 10; i++ ) {
20       printf( "%7d%13d\n", i, n[ i ] );
21    } /* end for */
22
23    return 0; /* indicates successful termination */
24
25 } /* end main */
```

for loop initializes each array element separately

for loop outputs all array elements

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

Outline

fig06_03.c

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Outline

fig06_04.c

(1 of 2)

```
1  /* Fig. 6.4: fig06_04.c
2     Initializing an array with an initializer list */
3  #include <stdio.h>
4
5  /* function main begins program execution */
6  int main( void )
7  {
8     /* use initializer list to initialize array n */
9     int n[ 10 ] = { 32, 27, 64, 18, 95, 14, 90, 70, 60, 37 };
10    int i; /* counter */
11
12    printf( "%s%13s\n", "Element", "Value" );
13
14    /* output contents of array in tabular format */
15    for ( i = 0; i < 10; i++ ) {
16       printf( "%7d%13d\n", i, n[ i ] );
17    } /* end for */
18
19    return 0; /* indicates successful termination */
20
21 } /* end main */
```

initializer list initializes all array elements simultaneously

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

Outline

fig06_04.c

(2 of 2)

Common Programming Error 6.2

Forgetting to initialize the elements of an array whose elements should be initialized.

Common Programming Error 6.3

Providing more initializers in an array initializer list than there are elements in the array is a syntax error.

Outline

```c
/* Fig. 6.5: fig06_05.c
   Initialize the elements of array s to the even integers from 2 to 20 */
#include <stdio.h>
#define SIZE 10 /* maximum size of array */

/* function main begins program execution */
int main( void )
{
   /* symbolic constant SIZE can be used to specify array size */
   int s[ SIZE ]; /* array s has SIZE elements */
   int j; /* counter */

   for ( j = 0; j < SIZE; j++ ) { /* set the values */
      s[ j ] = 2 + 2 * j;
   } /* end for */

   printf( "%s%13s\n", "Element", "Value" );

   /* output contents of array s in tabular format */
   for ( j = 0; j < SIZE; j++ ) {
      printf( "%7d%13d\n", j, s[ j ] );
   } /* end for */

   return 0; /* indicates successful termination */

} /* end main */
```

`#define` directive tells compiler to replace all instances of the word **`SIZE`** with **`10`**

fig06_05.c

(1 of 2)

`SIZE` is replaced with **`10`** by the compiler, so array **`s`** has 10 elements

`for` loop initializes each array element separately

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

Outline

fig06_05.c

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Common Programming Error 6.4

Ending a `#define` or `#include` preprocessor directive with a semicolon. Remember that preprocessor directives are not C statements.

Common Programming Error 6.5

Assigning a value to a symbolic constant in an executable statement is a syntax error. A symbolic constant is not a variable. No space is reserved for it by the compiler as with variables that hold values at execution time.

Software Engineering Observation 6.1

Defining the size of each array as a symbolic constant makes programs more scalable.

Good Programming Practice 6.1

Use only uppercase letters for symbolic constant names. This makes these constants stand out in a program and reminds you that symbolic constants are not variables.

Good Programming Practice 6.2

In multiword symbolic constant names, use underscores to separate the words for readability.

Outline

fig06_06.c

```
1  /* Fig. 6.6: fig06_06.c
2     Compute the sum of the elements of the array */
3  #include <stdio.h>
4  #define SIZE 12
5
6  /* function main begins program execution */
7  int main( void )
8  {
9     /* use initializer list to initialize array */
10    int a[ SIZE ] = { 1, 3, 5, 4, 7, 2, 99, 16, 45, 67, 89, 45 };
11    int i; /* counter */
12    int total = 0; /* sum of array */
13
14    /* sum contents of array a */
15    for ( i = 0; i < SIZE; i++ ) {
16       total += a[ i ];
17    } /* end for */
18
19    printf( "Total of array element values is %d\n", total );
20
21    return 0; /* indicates successful termination */
22
23 } /* end main */
```

initializer list initializes all array elements simultaneously

for loop adds each element of the array to variable **total**

```
Total of array element values is 383
```

Outline

```
1  /* Fig. 6.7: fig06_07.c
2     Student poll program */
3  #include <stdio.h>
4  #define RESPONSE_SIZE 40 /* define array sizes */
5  #define FREQUENCY_SIZE 11
6
7  /* function main begins program execution */
8  int main( void )
9  {
10    int answer; /* counter to loop through 40 responses */
11    int rating; /* counter to loop through frequencies 1-10 */
12
13    /* initialize frequency counters to 0 */
14    int frequency[ FREQUENCY_SIZE ] = { 0 };
15
16    /* place the survey responses in the responses array */
17    int responses[ RESPONSE_SIZE ] = { 1, 2, 6, 4, 8, 5, 9, 7, 8, 10,
18         1, 6, 3, 8, 6, 10, 3, 8, 2, 7, 6, 5, 7, 6, 8, 6, 7, 5, 6, 6,
19         5, 6, 7, 5, 6, 4, 8, 6, 8, 10 };
20
21    /* for each answer, select value of an element of array responses
22         and use that value as subscript in array frequency to
23         determine element to increment */
24    for ( answer = 0; answer < RESPONSE_SIZE; answer++ ) {
25       ++frequency[ responses [ answer ] ];
26    } /* end for */
27
```

`#define` directives create symbolic constants

`frequency` array is defined with 11 elements

`responses` array is defined with 40 elements and its elements are initialized

subscript of **`frequency`** array is given by value in **`responses`** array

`fig06_07.c`

(1 of 2)

```
28    /* display results */
29    printf( "%s%17s\n", "Rating", "Frequency" );
30
31    /* output the frequencies in a tabular format */
32    for ( rating = 1; rating < FREQUENCY_SIZE; rating++ ) {
33       printf( "%6d%17d\n", rating, frequency[ rating ] );
34    } /* end for */
35
36    return 0; /* indicates successful termination */
37
38 } /* end main */
```

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

Outline

fig06_07.c

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Good Programming Practice 6.3

Strive for program clarity. Sometimes it may be worthwhile to trade off the most efficient use of memory or processor time in favor of writing clearer programs.

Performance Tip 6.1

Sometimes performance considerations far outweigh clarity considerations.

Common Programming Error 6.6

Referring to an element outside the array bounds.

Error-Prevention Tip 6.1

When looping through an array, the array subscript should never go below 0 and should always be less than the total number of elements in the array (size – 1). Make sure the loop-terminating condition prevents accessing elements outside this range.

Error-Prevention Tip 6.2

Programs should validate the correctness of all input values to prevent erroneous information from affecting a program's calculations.

Outline

fig06_08.c

(1 of 2)

```
1  /* Fig. 6.8: fig06_08.c
2     Histogram printing program */
3  #include <stdio.h>
4  #define SIZE 10
5
6  /* function main begins program execution */
7  int main( void )
8  {
9     /* use initializer list to initialize array n */
10    int n[ SIZE ] = { 19, 3, 15, 7, 11, 9, 13, 5, 17, 1 };
11    int i; /* outer for counter for array elements */
12    int j; /* inner for counter counts *s in each histogram bar */
13
14    printf( "%s%13s%17s\n", "Element", "Value", "Histogram" );
15
16    /* for each element of array n, output a bar of the histogram */
17    for ( i = 0; i < SIZE; i++ ) {
18       printf( "%7d%13d          ", i, n[ i ]) ;
19
20       for ( j = 1; j <= n[ i ]; j++ ) { /* print one bar */
21          printf( "%c", '*' );
22        } /* end inner for */
23
24       printf( "\n" ); /* end a histogram bar */
25    } /* end outer for */
26
27    return 0; /* indicates successful termination */
28
29 } /* end main */
```

nested **for** loop prints n[**i**] asterisks on the **i**th line

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

Outline

fig06_08.c

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Outline

fig06_09.c

(1 of 2)

```
1  /* Fig. 6.9: fig06_09.c
2     Roll a six-sided die 6000 times */
3  #include <stdio.h>
4  #include <stdlib.h>
5  #include <time.h>
6  #define SIZE 7
7
8  /* function main begins program execution */
9  int main( void )
10 {
11    int face; /* random die value 1 - 6 */
12    int roll; /* roll counter 1-6000 */
13    int frequency[ SIZE ] = { 0 }; /* clear counts */
14
15    srand( time( NULL ) ); /* seed random-number generator */
16
17    /* roll die 6000 times */
18    for ( roll = 1; roll <= 6000; roll++ ) {
19       face = 1 + rand() % 6;
20       ++frequency[ face ]; /* replaces 26-line switch of Fig. 5.8 */
21    } /* end for */
```

`for` loop uses one array to track number of times each number is rolled instead of using 6 variables and a **`switch`** statement

Outline

```
22
23    printf( "%s%17s\n", "Face", "Frequency" );
24
25    /* output frequency elements 1-6 in tabular format */
26    for ( face = 1; face < SIZE; face++ ) {
27       printf( "%4d%17d\n", face, frequency[ face ] );
28    } /* end for */
29
30    return 0; /* indicates successful termination */
31
32 } /* end main */
```

```
Face        Frequency
   1             1029
   2              951
   3              987
   4             1033
   5             1010
   6              990
```

fig06_09.c

(2 of 2)

6.4 Array Examples

- **Character arrays**
  - **String "`first`" is really a static array of characters**
  - **Character arrays can be initialized using string literals**

```
char string1[] = "first";
```

    - **Null character `'\0'` terminates strings**
    - **`string1` actually has 6 elements**

It is equivalent to

```
char string1[] = { 'f', 'i', 'r', 's', 't', '\0' };
```

  - **Can access individual characters**

```
string1[ 3 ] is character 's'
```

  - **Array name is address of array, so & not needed for scanf**

```
scanf( "%s", string2 );
```

    - **Reads characters until whitespace encountered**
    - **Be careful not to write past end of array, as it is possible to do so**

Common Programming Error 6.7

Not providing `scanf` with a character array large enough to store a string typed at the keyboard can result in destruction of data in a program and other runtime errors. This can also make a system susceptible to worm and virus attacks.

Outline

fig06_10.c

(1 of 2)

```c
/* Fig. 6.10: fig06_10.c
   Treating character arrays as strings */
#include <stdio.h>

/* function main begins program execution */
int main( void )
{
   char string1[ 20 ]; /* reserves 20 characters */
   char string2[] = "string literal"; /* reserves 15 characters */
   int i; /* counter */

   /* read string from user into array string1 */
   printf("Enter a string: ");
   scanf( "%s", string1 ); /* input ended by whitespace character */

   /* output strings */
   printf( "string1 is: %s\nstring2 is: %s\n"
           "string1 with spaces between characters is:\n",
           string1, string2 );

   /* output characters until null character is reached */
   for ( i = 0; string1[ i ] != '\0'; i++ ) {
      printf( "%c ", string1[ i ] );
   } /* end for */

   printf( "\n" );

   return 0; /* indicates successful termination */

} /* end main */
```

string2 array is defined with one element for each character, so 15 elements including null character **/0**

for loop prints characters of **string1** array with spaces in between

```
Enter a string: Hello there
string1 is: Hello
string2 is: string literal
string1 with spaces between characters is:
H e l l o
```

Outline

fig06_10.c

(2 of 2)

Performance Tip 6.2

In functions that contain automatic arrays where the function is in and out of scope frequently, make the array `static` so it is not created each time the function is called.

Outline

```c
/* Fig. 6.11: fig06_11.c
   Static arrays are initialized to zero */
#include <stdio.h>

void staticArrayInit( void );    /* function prototype */
void automaticArrayInit( void ); /* function prototype */

/* function main begins program execution */
int main( void )
{
   printf( "First call to each function:\n" );
   staticArrayInit();
   automaticArrayInit();

   printf( "\n\nSecond call to each function:\n" );
   staticArrayInit();
   automaticArrayInit();

   return 0; /* indicates successful termination */

} /* end main */

```

fig06_11.c

(1 of 4)

Outline

```
23 /* function to demonstrate a static local array */
24 void staticArrayInit( void )
25 {
26    /* initializes elements to 0 first time function is called */
27    static int array1[ 3 ];
28    int i; /* counter */
29
30    printf( "\nValues on entering staticArrayInit:\n" );
31
32    /* output contents of array1 */
33    for ( i = 0; i <= 2; i++ ) {
34       printf( "array1[ %d ] = %d  ", i, array1[ i ] );
35    } /* end for */
36
37    printf( "\nValues on exiting staticArrayInit:\n" );
38
39    /* modify and output contents of array1 */
40    for ( i = 0; i <= 2; i++ ) {
41       printf( "array1[ %d ] = %d  ", i, array1[ i ] += 5 );
42    } /* end for */
43
44 } /* end function staticArrayInit */
```

`static` array is created only once, when **`staticArrayInit`** is first called

`fig06_11.c`

(2 of 4)

Outline

```
45
46 /* function to demonstrate an automatic local array */
47 void automaticArrayInit( void )
48 {
49    /* initializes elements each time function is called */
50    int array2[ 3 ] = { 1, 2, 3 };
51    int i; /* counter */
52
53    printf( "\n\nValues on entering automaticArrayInit:\n" );
54
55    /* output contents of array2 */
56    for ( i = 0; i <= 2; i++ ) {
57       printf("array2[ %d ] = %d  ", i, array2[ i ] );
58    } /* end for */
59
60    printf( "\nValues on exiting automaticArrayInit:\n" );
61
62    /* modify and output contents of array2 */
63    for ( i = 0; i <= 2; i++ ) {
64       printf( "array2[ %d ] = %d  ", i, array2[ i ] += 5 );
65    } /* end for */
66
67 } /* end function automaticArrayInit */
```

automatic array is recreated every time **`automaticArrayInit`** is called

`fig06_11.c`

```
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
```

Outline

fig06_11.c

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Common Programming Error 6.8

Assuming that elements of a local `static` array are initialized to zero every time the function in which the array is defined is called.

6.5 Passing Arrays to Functions

- **Passing arrays**
  - **To pass an array argument to a function, specify the name of the array without any brackets**

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

    - **Array size usually passed to function**
  - **Arrays passed call-by-reference**
  - **Name of array is address of first element**
  - **Function knows where the array is stored**
    - **Modifies original memory locations**
- **Passing array elements**
  - **Passed by call-by-value**
  - **Pass subscripted name (i.e., `myArray[ 3 ]`) to function**

6.5 Passing Arrays to Functions

- **Function prototype**

```
void modifyArray( int b[], int arraySize );
```

  - **Parameter names optional in prototype**
    - `int b[]` could be written `int []`
    - `int arraySize` could be simply `int`

Performance Tip 6.3

Passing arrays by reference makes sense for performance reasons. If arrays were passed by value, a copy of each element would be passed. For large, frequently passed arrays, this would be time consuming and would consume considerable storage for the copies of the arrays.

Outline

fig06_12.c

```c
/* Fig. 6.12: fig06_12.c
   The name of an array is the same as &array[ 0 ] */
#include <stdio.h>

/* function main begins program execution */
int main( void )
{
   char array[ 5 ]; /* define an array of size 5 */

   printf( "    array = %p\n&array[0] = %p\n   &array = %p\n",
      array, &array[ 0 ], &array );

   return 0; /* indicates successful termination */

} /* end main */
```

```
    array = 0012FF78
&array[0] = 0012FF78
   &array = 0012FF78
```

Software Engineering Observation 6.2

It is possible to pass an array by value (by using a simple trick we explain in Chapter 10).

Outline

```c
/* Fig. 6.13: fig06_13.c
   Passing arrays and individual array elements to functions */
#include <stdio.h>
#define SIZE 5

/* function prototypes */
void modifyArray( int b[], int size );
void modifyElement( int e );

/* function main begins program execution */
int main( void )
{
   int a[ SIZE ] = { 0, 1, 2, 3, 4 }; /* initialize a */
   int i; /* counter */

   printf( "Effects of passing entire array by reference:\n\nThe "
          "values of the original array are:\n" );

   /* output original array */
   for ( i = 0; i < SIZE; i++ ) {
      printf( "%3d", a[ i ] );
   } /* end for */

   printf( "\n" );

   /* pass array a to modifyArray by reference */
   modifyArray( a, SIZE );

   printf( "The values of the modified array are:\n" );

```

Function prototype indicates function will take an array

Array **a** is passed to **modifyArray** by passing only its name

fig06_13.c

(1 of 3)

Outline

fig06_13.c

(2 of 3)

```
31    /* output modified array */
32    for ( i = 0; i < SIZE; i++ ) {
33       printf( "%3d", a[ i ] );
34    } /* end for */
35
36    /* output value of a[ 3 ] */
37    printf( "\n\n\nEffects of passing array element "
38            "by value:\n\nThe value of a[3] is %d\n", a[ 3 ] );
39
40    modifyElement( a[ 3 ] ); /* pass array element a[ 3 ] by value */
41
42    /* output value of a[ 3 ] */
43    printf( "The value of a[ 3 ] is %d\n", a[ 3 ] );
44
45    return 0; /* indicates successful termination */
46
47 } /* end main */
48
49 /* in function modifyArray, "b" points to the original array "a"
50    in memory */
51 void modifyArray( int b[], int size )
52 {
53    int j; /* counter */
54
55    /* multiply each array element by 2 */
56    for ( j = 0; j < size; j++ ) {
57       b[ j ] *= 2;
58    } /* end for */
59
60 } /* end function modifyArray */
```

Array element is passed to **modifyElement** by passing **a[3]**

Outline

```
61
62 /* in function modifyElement, "e" is a local copy of array element
63    a[ 3 ] passed from main */
64 void modifyElement( int e )
65 {
66    /* multiply parameter by 2 */
67    printf( "Value in modifyElement is %d\n", e *= 2 );
68 } /* end function modifyElement */
```

```
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
```

fig06_13.c

(3 of 3)

Outline

fig06_14.c

(1 of 2)

```c
/* Fig. 6.14: fig06_14.c
   Demonstrating the const type qualifier with arrays */
#include <stdio.h>

void tryToModifyArray( const int b[] ); /* function prototype */

/* function main begins program execution */
int main( void )
{
   int a[] = { 10, 20, 30 }; /* initialize a */

   tryToModifyArray( a );

   printf("%d %d %d\n", a[ 0 ], a[ 1 ], a[ 2 ] );

   return 0; /* indicates successful termination */

} /* end main */

/* in function tryToModifyArray, array b is const, so it cannot be
   used to modify the original array a in main. */
void tryToModifyArray( const int b[] )
{
   b[ 0 ] /= 2;    /* error */
   b[ 1 ] /= 2;    /* error */
   b[ 2 ] /= 2;    /* error */
} /* end function tryToModifyArray */
```

`const` qualifier tells compiler that array cannot be changed

Any attempts to modify the array will result in errors

```
Compiling...
FIG06_14.C
fig06_14.c(24) : error C2166: l-value specifies const object
fig06_14.c(25) : error C2166: l-value specifies const object
fig06_14.c(26) : error C2166: l-value specifies const object
```

Outline

fig06_14.c

(2 of 2)

Software Engineering Observation 6.3

The `const` type qualifier can be applied to an array parameter in a function definition to prevent the original array from being modified in the function body. This is another example of the principle of least privilege. Functions should not be given the capability to modify an array unless it is absolutely necessary.

6.6 Sorting Arrays

- **Sorting data**
  - **Important computing application**
  - **Virtually every organization must sort some data**
- **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**
- **Example:**
  - **original: 3 4 2 6 7**
  - **pass 1: 3 2 4 6 7**
  - **pass 2: 2 3 4 6 7**
  - **Small elements "bubble" to the top**

Performance Tip 6.4

Often, the simplest algorithms perform poorly. Their virtue is that they are easy to write, test and debug. However, more complex algorithms are often needed to realize maximum performance.

Outline

fig06_15.c

(1 of 2)

```c
/* Fig. 6.15: fig06_15.c
   This program sorts an array's values into ascending order */
#include <stdio.h>
#define SIZE 10

/* function main begins program execution */
int main( void )
{
   /* initialize a */
   int a[ SIZE ] = { 2, 6, 4, 8, 10, 12, 89, 68, 45, 37 };
   int pass; /* passes counter */
   int i;    /* comparisons counter */
   int hold; /* temporary location used to swap array elements */

   printf( "Data items in original order\n" );

   /* output original array */
   for ( i = 0; i < SIZE; i++ ) {
      printf( "%4d", a[ i ] );
   } /* end for */

   /* bubble sort */
   /* loop to control number of passes */
   for ( pass = 1; pass < SIZE; pass++ ) {

      /* loop to control number of comparisons per pass */
      for ( i = 0; i < SIZE - 1; i++ ) {

```

Outline

fig06_15.c

(2 of 2)

```
29          /* compare adjacent elements and swap them if first
30          element is greater than second element */
31          if ( a[ i ] > a[ i + 1 ] ) {
32             hold = a[ i ];
33             a[ i ] = a[ i + 1 ];
34             a[ i + 1 ] = hold;
35          } /* end if */
36
37       } /* end inner for */
38
39    } /* end outer for */
40
41    printf( "\nData items in ascending order\n" );
42
43    /* output sorted array */
44    for ( i = 0; i < SIZE; i++ ) {
45       printf( "%4d", a[ i ] );
46    } /* end for */
47
48    printf( "\n" );
49
50    return 0; /* indicates successful termination */
51 }
```

If any two array elements are out of order, the function swaps them

```
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
```

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

- **Mean – average**
- **Median – number in middle of sorted list**
  - **1, 2, 3, 4, 5**
  - **3 is the median**
- **Mode – number that occurs most often**
  - **1, 1, 1, 2, 3, 3, 4, 5**
  - **1 is the mode**

Outline

fig06_16.c

(1 of 6)

```
/* Fig. 6.16: fig06_16.c
   This program introduces the topic of survey data analysis.
   It computes the mean, median and mode of the data */
#include <stdio.h>
#define SIZE 99

/* function prototypes */
void mean( const int answer[] );
void median( int answer[] );
void mode( int freq[], const int answer[] ) ;
void bubbleSort( int a[] );
void printArray( const int a[] );

/* function main begins program execution */
int main( void )
{
   int frequency[ 10 ] = { 0 }; /* initialize array frequency */

   /* initialize array response */
   int response[ SIZE ] =
      { 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 };
```

Outline

fig06_16.c

(2 of 6)

```
31
32    /* process responses */
33    mean( response );
34    median( response );
35    mode( frequency, response );
36
37    return 0; /* indicates successful termination */
38
39 } /* end main */
40
41 /* calculate average of all response values */
42 void mean( const int answer[] )
43 {
44    int j; /* counter for totaling array elements */
45    int total = 0; /* variable to hold sum of array elements */
46
47    printf( "%s\n%s\n%s\n", "********", "  Mean", "********" );
48
49    /* total response values */
50    for ( j = 0; j < SIZE; j++ ) {
51       total += answer[ j ];
52    } /* end for */
53
54    printf( "The mean is the average value of the data\n"
55            "items. The mean is equal to the total of\n"
56            "all the data items divided by the number\n"
57            "of data items ( %d ). The mean value for\n"
58            "this run is: %d / %d = %.4f\n\n",
59            SIZE, total, SIZE, (  double  ) total / SIZE );
60 } /* end function mean */
```

Outline

fig06_16.c

(3 of 6)

```
61
62 /* sort array and determine median element's value */
63 void median( int answer[] )
64 {
65    printf( "\n%s\n%s\n%s\n%s",
66            "*********", " Median", "*********",
67            "The unsorted array of responses is" );
68
69    printArray( answer ); /* output unsorted array */
70
71    bubbleSort( answer ); /* sort array */
72
73    printf( "\n\nThe sorted array is" );
74    printArray( answer ); /* output sorted array */
75
76    /* display median element */
77    printf( "\n\nThe median is element %d of\n"
78            "the sorted %d element array.\n"
79            "For this run the median is %d\n\n",
80            SIZE / 2, SIZE, answer[ SIZE / 2 ] );
81 } /* end function median */
82
83 /* determine most frequent response */
84 void mode( int freq[], const int answer[] )
85 {
86    int rating; /* counter for accessing elements 1-9 of array freq */
87    int j; /* counter for summarizing elements 0-98 of array answer */
88    int h; /* counter for diplaying histograms of elements in array freq */
89    int largest = 0; /* represents largest frequency */
90    int modeValue = 0; /* represents most frequent response */
```

Once the array is sorted, the median will be the value of the middle element

Outline

fig06_16.c

(4 of 6)

```
91
92    printf( "\n%s\n%s\n%s\n",
93            "*********", "  Mode", "*********" );
94
95    /* initialize frequencies to 0 */
96    for ( rating = 1; rating <= 9; rating++ ) {
97       freq[ rating ] = 0;
98    } /* end for */
99
100   /* summarize frequencies */
101   for ( j = 0; j < SIZE; j++ ) {
102      ++freq[ answer[ j ] ];
103   } /* end for */
104
105   /* output headers for result columns */
106   printf( "%s%11s%19s\n\n%54s\n%54s\n\n",
107           "Response", "Frequency", "Histogram",
108           "1    1    2    2", "5    0    5    0    5" );
109
110   /* output results */
111   for ( rating = 1; rating <= 9; rating++ ) {
112      printf( "%8d%11d          ", rating, freq[ rating ] );
113
114      /* keep track of mode value and largest frequency value */
115      if ( freq[ rating ] > largest ) {
116         largest = freq[ rating ];
117         modeValue = rating;
118      } /* end if */
```

Outline

fig06_16.c

(5 of 6)

```
119
120      /* output histogram bar representing frequency value */
121      for ( h = 1; h <= freq[ rating ]; h++ ) {
122         printf( "*" );
123      } /* end inner for */
124
125      printf( "\n" ); /* being new line of output */
126   } /* end outer for */
127
128   /* display the mode value */
129   printf( "The mode is the most frequent value.\n"
130           "For this run the mode is %d which occurred"
131           " %d times.\n", modeValue, largest );
132 } /* end function mode */
133
134 /* function that sorts an array with bubble sort algorithm */
135 void bubbleSort( int a[] )
136 {
137   int pass; /* pass counter */
138   int j;    /* comparison counter */
139   int hold; /* temporary location used to swap elements */
140
141   /* loop to control number of passes */
142   for ( pass = 1; pass < SIZE; pass++ ) {
143
144      /* loop to control number of comparisons per pass */
145      for ( j = 0; j < SIZE - 1; j++ ) {
146
```

Outline

fig06_16.c

(6 of 6)

```
147         /* swap elements if out of order */
148         if ( a[ j ] > a[ j + 1 ] ) {
149            hold = a[ j ];
150            a[ j ] = a[ j + 1 ];
151            a[ j + 1 ] = hold;
152         } /* end if */
153
154      } /* end inner for */
155
156   } /* end outer for */
157
158 } /* end function bubbleSort */
159
160 /* output array contents (20 values per row) */
161 void printArray( const int a[] )
162 {
163   int j; /* counter */
164
165   /* output array contents */
166   for ( j = 0; j < SIZE; j++ ) {
167
168      if ( j % 20 == 0 ) { /* begin new line every 20 values */
169         printf( "\n" );
170      } /* end if */
171
172      printf( "%2d", a[ j ] );
173   } /* end for */
174
175 } /* end function printArray */
```

```
********
  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
```

(continued on next slide…)

Outline

(1 of 2)

(continued from previous slide…)

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

********
  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.
```

Outline

(2 of 2)

6.8 Searching Arrays

- **Search an array for a *key value***
- **Linear search**
  - **Simple**
  - **Compare each element of array with key value**
  - **Useful for small and unsorted arrays**

Outline

fig06_18.c

(1 of 3)

```c
/* Fig. 6.18: fig06_18.c
   Linear search of an array */
#include <stdio.h>
#define SIZE 100

/* function prototype */
int linearSearch( const int array[], int key, int size );

/* function main begins program execution */
int main( void )
{
   int a[ SIZE ]; /* create array a */
   int x; /* counter for initializing elements 0-99 of array a */
   int searchKey; /* value to locate in array a */
   int element; /* variable to hold location of searchKey or -1 */

   /* create data */
   for ( x = 0; x < SIZE; x++ ) {
      a[ x ] = 2 * x;
   } /* end for */

```

Outline

fig06_18.c

(2 of 3)

```
22    printf( "Enter integer search key:\n" );
23    scanf( "%d", &searchKey );
24
25    /* attempt to locate searchKey in array a */
26    element = linearSearch( a, searchKey, SIZE );
27
28    /* display results */
29    if ( element != -1 ) {
30       printf( "Found value in element %d\n", element );
31    } /* end if */
32    else {
33       printf( "Value not found\n" );
34    } /* end else */
35
36    return 0; /* indicates successful termination */
37
38 } /* end main */
39
40 /* compare key to every element of array until the location is found
41    or until the end of array is reached; return subscript of element
42    if key or -1 if key is not found */
43 int linearSearch( const int array[], int key, int size )
44 {
45    int n; /* counter */
46
```

Outline

```
47    /* loop through array */
48    for ( n = 0; n < size; ++n ) {
49
50       if ( array[ n ] == key ) {
51          return n; /* return location of key */
52       } /* end if */
53
54    } /* end for */
55
56    return -1; /* key not found */
57
58 } /* end function linearSearch */
```

Linear search algorithm searches through every element in the array until a match is found

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

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

fig06_18.c

(3 of 3)

6.8 Searching Arrays

- **Binary search**
  - For sorted arrays only
  - Compares `middle` element with `key`
    - If equal, match found
    - If `key < middle`, looks in first half of array
    - If `key > middle`, looks in last half
    - Repeat
  - Very fast; at most n steps, where 2^n > number of elements
    - 30 element array takes at most 5 steps

      2^5 > 30 so at most 5 steps

Outline

fig06_19.c

(1 of 6)

```c
/* Fig. 6.19: fig06_19.c
   Binary search of an array */
#include <stdio.h>
#define SIZE 15

/* function prototypes */
int binarySearch( const int b[], int searchKey, int low, int high );
void printHeader( void );
void printRow( const int b[], int low, int mid, int high );

/* function main begins program execution */
int main( void )
{
   int a[ SIZE ]; /* create array a */
   int i; /* counter for initializing elements 0-14 of array a */
   int key; /* value to locate in array a */
   int result; /* variable to hold location of key or -1 */

   /* create data */
   for ( i = 0; i < SIZE; i++ ) {
      a[ i ] = 2 * i;
   } /* end for */

   printf( "Enter a number between 0 and 28: " );
   scanf( "%d", &key );

   printHeader();

   /* search for key in array a */
   result = binarySearch( a, key, 0, SIZE - 1 );
```

Outline

fig06_19.c

(2 of 6)

```
31
32    /* display results */
33    if ( result != -1 ) {
34       printf( "\n%d found in array element %d\n", key, result );
35    } /* end if */
36    else {
37       printf( "\n%d not found\n", key );
38    } /* end else */
39
40    return 0; /* indicates successful termination */
41
42 } /* end main */
43
44 /* function to perform binary search of an array */
45 int binarySearch( const int b[], int searchKey, int low, int high )
46 {
47    int middle; /* variable to hold middle element of array */
48
49    /* loop until low subscript is greater than high subscript */
50    while ( low <= high ) {
51
52       /* determine middle element of subarray being searched */
53       middle = ( low + high ) / 2;
54
55       /* display subarray used in this loop iteration */
56       printRow( b, low, middle, high );
57
```

Outline

fig06_19.c

(3 of 6)

```
58       /* if searchKey matched middle element, return middle */
59       if ( searchKey == b[ middle ] ) {
60          return middle;
61       } /* end if */
62
63       /* if searchKey less than middle element, set new high */
64       else if ( searchKey < b[ middle ] ) {
65          high = middle - 1; /* search low end of array */
66       } /* end else if */
67
68       /* if searchKey greater than middle element, set new low */
69       else {
70          low = middle + 1; /* search high end of array */
71       } /* end else */
72
73    } /* end while */
74
75    return -1;   /* searchKey not found */
76
77 } /* end function binarySearch */
78
79 /* Print a header for the output */
80 void printHeader( void )
81 {
82    int i; /* counter */
83
84    printf( "\nSubscripts:\n" );
85
```

If value is found, return its index

If value is too high, search the left half of array

If value is too low, search the right half of array

Outline

fig06_19.c

(4 of 6)

```
86    /* output column head */
87    for ( i = 0; i < SIZE; i++ ) {
88       printf( "%3d ", i );
89    } /* end for */
90
91    printf( "\n" ); /* start new line of output */
92
93    /* output line of - characters */
94    for ( i = 1; i <= 4 * SIZE; i++ ) {
95       printf( "-" );
96    } /* end for */
97
98    printf( "\n" ); /* start new line of output */
99 } /* end function printHeader */
100
101 /* Print one row of output showing the current
102    part of the array being processed. */
103 void printRow( const int b[], int low, int mid, int high )
104 {
105    int i; /* counter for iterating through array b */
106
```

Outline

fig06_19.c

(5 of 6)

```
107   /* loop through entire array */
108   for ( i = 0; i < SIZE; i++ ) {
109
110      /* display spaces if outside current subarray range */
111      if ( i < low || i > high ) {
112         printf( "    " );
113      } /* end if */
114      else if ( i == mid ) { /* display middle element */
115         printf( "%3d*", b[ i ] ); /* mark middle value */
116      } /* end else if */
117      else { /* display other elements in subarray */
118         printf( "%3d ", b[ i ] );
119      } /* end else */
120
121   } /* end for */
122
123   printf( "\n" ); /* start new line of output */
124} /* end function printRow */
```

```
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
```

(continued on next slide…)

(continued from previous slide…)

```
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
```

```
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
```

Outline

fig06_19.c

(6 of 6)

6.9 Multiple-Subscripted Arrays

- **Multiple subscripted arrays**
  - Tables with rows and columns (`m` by `n` array)
  - Like matrices: specify row, then column
- **Initialization**
  - `int b[2][2] = { { 1, 2 }, { 3, 4 } };`
  - Initializers grouped by row in braces
  - If not enough, unspecified elements set to zero

    ```
    int b[2][2] = { { 1 }, { 3, 4 } };
    ```
- **Referencing elements**
  - Specify row, then column

    ```
    printf( "%d", b[0][1] );
    ```

Common Programming Error 6.9

Referencing a double-subscripted array element as `a[ x, y ]` instead of `a[ x ][ y ]`. C interprets `a[ x, y ]` as `a[ y ]`, and as such it does not cause a syntax error.

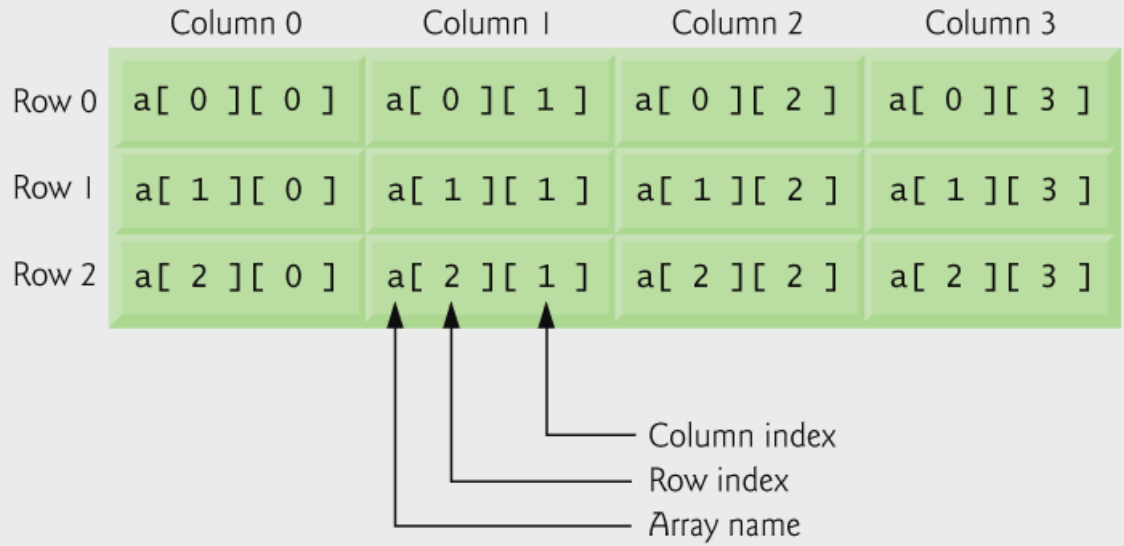

Fig. 6.20 | Double-subscripted array with three rows and four columns.

Outline

fig06_21.c

(1 of 2)

```
1  /* Fig. 6.21: fig06_21.c
2     Initializing multidimensional arrays */
3  #include <stdio.h>
4
5  void printArray( const int a[][ 3 ] ); /* function prototype */
6
7  /* function main begins program execution */
8  int main( void )
9  {
10    /* initialize array1, array2, array3 */
11    int array1[ 2 ][ 3 ] = { { 1, 2, 3 }, { 4, 5, 6 } };
12    int array2[ 2 ][ 3 ] = { 1, 2, 3, 4, 5 };
13    int array3[ 2 ][ 3 ] = { { 1, 2 }, { 4 } };
14
15    printf( "Values in array1 by row are:\n" );
16    printArray( array1 );
17
18    printf( "Values in array2 by row are:\n" );
19    printArray( array2 );
20
21    printf( "Values in array3 by row are:\n" );
22    printArray( array3 );
23
24    return 0; /* indicates successful termination */
25
26 } /* end main */
27
```

array1 is initialized with both rows full

array2 and **array3** are initialized only partially

Outline

fig06_21.c

(2 of 2)

```
28 /* function to output array with two rows and three columns */
29 void printArray( const int a[][ 3 ] )
30 {
31    int i; /* row counter */
32    int j; /* column counter */
33
34    /* loop through rows */
35    for ( i = 0; i <= 1; i++ ) {
36
37       /* output column values */
38       for ( j = 0; j <= 2; j++ ) {
39          printf( "%d ", a[ i ][ j ] );
40       } /* end inner for */
41
42       printf( "\n" ); /* start new line of output */
43    } /* end outer for */
44
45 } /* end function printArray */
```

```
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
```

Outline

fig06_22.c

(1 of 6)

```
1  /* Fig. 6.22: fig06_22.c
2     Double-subscripted array example */
3  #include <stdio.h>
4  #define STUDENTS 3
5  #define EXAMS 4
6
7  /* function prototypes */
8  int minimum( const int grades[][ EXAMS ], int pupils, int tests );
9  int maximum( const int grades[][ EXAMS ], int pupils, int tests );
10 double average( const int setOfGrades[], int tests );
11 void printArray( const int grades[][ EXAMS ], int pupils, int tests );
12
13 /* function main begins program execution */
14 int main( void )
15 {
16    int student; /* student counter */
17
18    /* initialize student grades for three students (rows) */
19    const int studentGrades[ STUDENTS ][ EXAMS ] =
20       { { 77, 68, 86, 73 },
21         { 96, 87, 89, 78 },
22         { 70, 90, 86, 81 } };
23
24    /* output array studentGrades */
25    printf( "The array is:\n" );
26    printArray( studentGrades, STUDENTS, EXAMS );
27
```

Each row in the array corresponds to a single student's set of grades

```
28    /* determine smallest and largest grade values */
29    printf( "\n\nLowest grade: %d\nHighest grade: %d\n",
30       minimum( studentGrades, STUDENTS, EXAMS ),
31       maximum( studentGrades, STUDENTS, EXAMS ) );
32
33    /* calculate average grade for each student */
34    for ( student = 0; student < STUDENTS; student++ ) {
35       printf( "The average grade for student %d is %.2f\n",
36          student, average( studentGrades[ student ], EXAMS ) );
37    } /* end for */
38
39    return 0; /* indicates successful termination */
40
41 } /* end main */
42
```

average function is passed a row of the array

Outline

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```
43 /* Find the minimum grade */
44 int minimum( const int grades[][ EXAMS ], int pupils, int tests )
45 {
46    int i; /* student counter */
47    int j; /* exam counter */
48    int lowGrade = 100; /* initialize to highest possible grade */
49
50    /* loop through rows of grades */
51    for ( i = 0; i < pupils; i++ ) {
52
53       /* loop through columns of grades */
54       for ( j = 0; j < tests; j++ ) {
55
56          if ( grades[ i ][ j ] < lowGrade ) {
57             lowGrade = grades[ i ][ j ];
58          } /* end if */
59
60       } /* end inner for */
61
62    } /* end outer for */
63
64    return lowGrade; /* return minimum grade */
65
66 } /* end function minimum */
67
```

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```
68 /* Find the maximum grade */
69 int maximum( const int grades[][ EXAMS ], int pupils, int tests )
70 {
71    int i; /* student counter */
72    int j; /* exam counter */
73    int highGrade = 0; /* initialize to lowest possible grade */
74
75    /* loop through rows of grades */
76    for ( i = 0; i < pupils; i++ ) {
77
78       /* loop through columns of grades */
79       for ( j = 0; j < tests; j++ ) {
80
81          if ( grades[ i ][ j ] > highGrade ) {
82             highGrade = grades[ i ][ j ];
83          } /* end if */
84
85       } /* end inner for */
86
87    } /* end outer for */
88
89    return highGrade; /* return maximum grade */
90
91 } /* end function maximum */
92
```

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```
93 /* Determine the average grade for a particular student */
94 double average( const int setOfGrades[], int tests )
95 {
96    int i; /* exam counter */
97    int total = 0; /* sum of test grades */
98
99    /* total all grades for one student */
100   for ( i = 0; i < tests; i++ ) {
101      total += setOfGrades[ i ];
102   } /* end for */
103
104   return ( double ) total / tests; /* average */
105
106 } /* end function average */
107
108 /* Print the array */
109 void printArray( const int grades[][ EXAMS ], int pupils, int tests )
110 {
111   int i; /* student counter */
112   int j; /* exam counter */
113
114   /* output column heads */
115   printf( "                [0]  [1]  [2]  [3]" );
116
```

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```
117   /* output grades in tabular format */
118   for ( i = 0; i < pupils; i++ ) {
119
120      /* output label for row */
121      printf( "\nstudentGrades[%d] ", i );
122
123      /* output grades for one student */
124      for ( j = 0; j < tests; j++ ) {
125         printf( "%-5d", grades[ i ][ j ] );
126      } /* end inner for */
127
128   } /* end outer for */
129
130} /* end function printArray */
```

```
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
```