C Pointers

Outline

7.1 Introduction

- **Pointers**
  - **Powerful, but difficult to master**
  - **Simulate call-by-reference**
  - **Close relationship with arrays and strings**

7.2 Pointer Variable Definitions and Initialization

- **Pointer variables**
  - **Contain memory addresses as their values**
  - **Normal variables contain a specific value (direct reference)**
  - **Pointers contain address of a variable that has a specific value (indirect reference)**
  - **Indirection – referencing a pointer value**

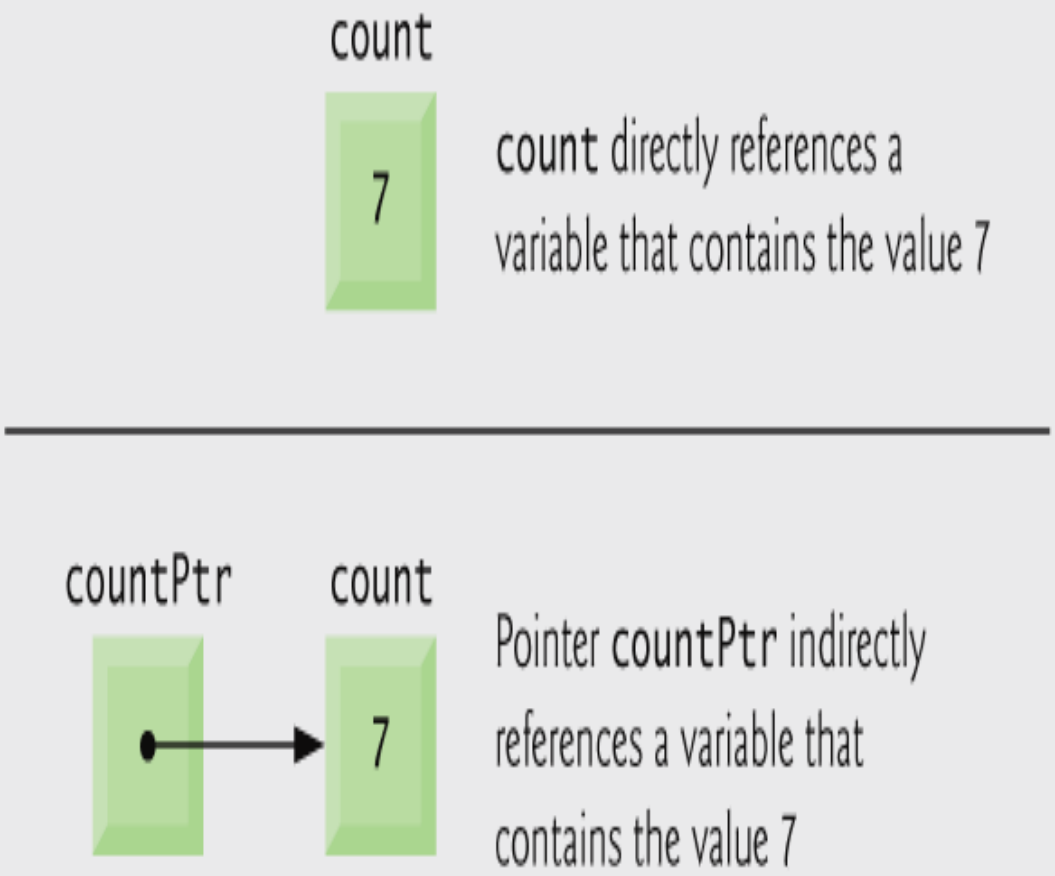


Fig. 7.1 | Directly and indirectly referencing a variable.

7.2 Pointer Variable Definitions and Initialization

- **Pointer definitions**
  - `*` **used with pointer variables**

```
int *myPtr;
```

  - **Defines a pointer to an** `int` **(pointer of type** `int *`**)**
  - **Multiple pointers require using a * before each variable definition**

```
int *myPtr1, *myPtr2;
```

  - **Can define pointers to any data type**
  - **Initialize pointers to** `0`**,** `NULL`**, or an address**
    - `0` **or** `NULL` **– points to nothing (**`NULL` **preferred)**

Common Programming Error 7.1

The asterisk (*) notation used to declare pointer variables does not distribute to all variable names in a declaration. Each pointer must be declared with the * prefixed to the name; e.g., if you wish to declare `xPtr` and `yPtr` as int pointers, use `int *xPtr, *yPtr;`.

Good Programming Practice 7.1

Include the letters `ptr` in pointer variable names to make it clear that these variables are pointers and thus need to be handled appropriately.

Error-Prevention Tip 7.1

Initialize pointers to prevent unexpected results.

Assignment revisited – Pointers and Vars

X = 17;

lvalue = rvalue

lvalue: expression that evaluates to a location

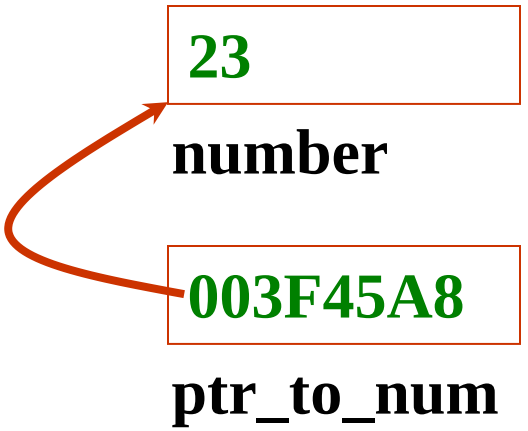
rvalue: expression that evaluates to a value

Simple Pointers

Pointer is a value that points to a location in the memory

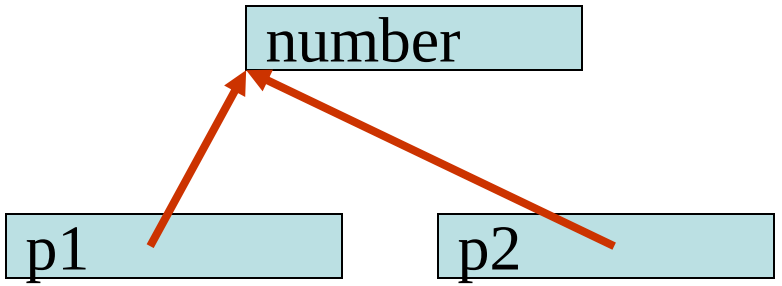
Pointer is associated with a type

```
int number ;
int * ptr_to_num ;

number = 23;
ptr_to_num = & number;
printf("Value is %d \n", (*ptr_to_num) );
```



More Pointers

```
int  number ;
int  * p1,  * p2;


p1 = & number ;
number = 23;
p2 = & number ;
printf(" *p1 = %d   *p2 = %d ", *p1, *p2);

/* Output ?? */
```

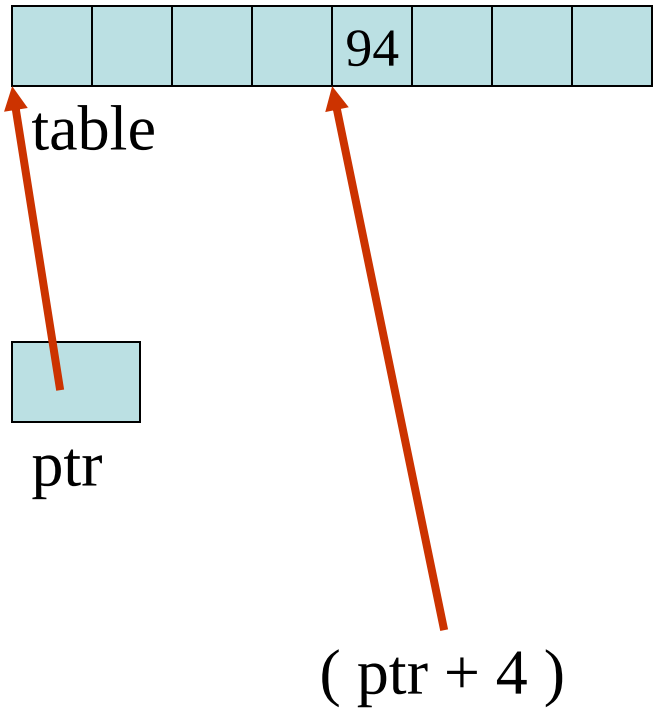


Pointers and Arrays

```
char str[32];
char *ptr;

ptr = str ;

strcpy( str, "test" );
strcpy( ptr, "test" );      /* does the same as above */
```

Pointers and Arrays

```
int table [8];
int *ptr ;

ptr = table ;

table [ 4 ] = 94;
*( ptr + 4 ) = 94;
```



How about

ptr = & table[0]?? vs. ptr=table;??

Pointer operations

Can add and subtract numbers (like array indices)

Can increment and decrement!

```
char str[] = "Test";
char * p ;
int i;

for( p = str, i=0;  *p != '\0';  p++,  i++);
printf(" The length of the string is %d ", i);
```

Interesting Example!

NULL pointer

A way to tell that pointer points to nothing

```
void main()
{
        char *msg = NULL;
        MyPrint( msg );
}

void MyPrint( char * txt )
{
        if ( txt == NULL )
                printf( "Invalid parameters: NULL pointer received\n");
        else
                printf( "%s\n", txt );
}
```

Command Line Arguments

```
/* MyProg.c    */
int main ( int argc , char *argv[] )
{ ...
```

```
> myProg   one   two   three
```

argc = 4
argv[0] = "myProg"
argv[1] = "one"
argv[2] = "two"
argv[3] = "three“
argv[4] = NULL

7.3 Pointer Operators

- & (address operator)
  - Returns address of operand

```
int y = 5;
int *yPtr;
yPtr = &y;     /* yPtr gets address of y */
yPtr “points to” y
```

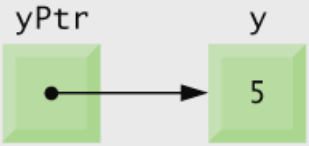


Fig. 7.2 | Graphical representation of a pointer pointing to an integer variable in memory.

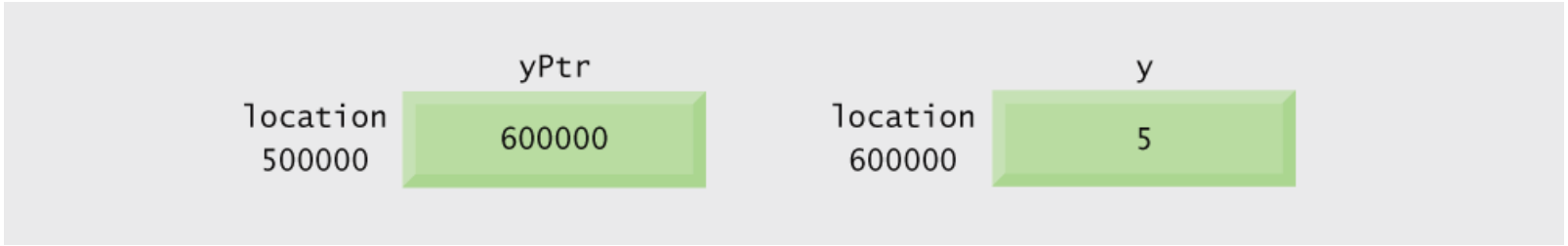


Fig. 7.3 | Representation of **`y`** and **`yPtr`** in memory.

7.3 Pointer Operators

- * (indirection/dereferencing operator)
  - Returns a synonym/alias of what its operand points to
  - *yptr returns y (because yptr points to y)
  - * can be used for assignment
    - Returns alias to an object

```
*yptr = 7;  /* changes y to 7 */
```

Key Line!

  - Dereferenced pointer (operand of *) must be an lvalue (no constants)
- * and & are inverses
  - They cancel each other out

Common Programming Error 7.2

Dereferencing a pointer that has not been properly initialized or that has not been assigned to point to a specific location in memory is an error. This could cause a fatal execution-time error, or it could accidentally modify important data and allow the program to run to completion with incorrect results.

Outline

fig07_04.c

(1 of 2)

```
1  /* Fig. 7.4: fig07_04.c
2     Using the & and * operators */
3  #include <stdio.h>
4
5  int main( void )
6  {
7     int a;        /* a is an integer */
8     int *aPtr;    /* aPtr is a pointer to an integer */
9
10    a = 7;
11    aPtr = &a;    /* aPtr set to address of a */
12
13    printf( "The address of a is %p"
14            "\nThe value of aPtr is %p", &a, aPtr );
15
16    printf( "\n\nThe value of a is %d"
17            "\nThe value of *aPtr is %d", a, *aPtr );
18
19    printf( "\n\nShowing that * and & are complements of "
20            "each other\n&*aPtr = %p"
21            "\n*&aPtr = %p\n", &*aPtr, *&aPtr );
22
23    return 0; /* indicates successful termination */
24
25 } /* end main */
```

If **aPtr** points to **a**, then **&a** and **aPtr** have the same value.

%p means Pointer type data.

a and ***aPtr** have the same value

&*aPtr and ***&aPtr** have the same value

```
The address of a is 0012FF7C
The value of aPtr is 0012FF7C

The value of a is 7
The value of *aPtr is 7

Showing that * and & are complements of each other.
&*aPtr = 0012FF7C
*&aPtr = 0012FF7C
```

Outline

fig07_04.c

(2 of 2)

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. 7.5 | Operator precedence.

7.4 Calling Functions by Reference

- **Call by reference with pointer arguments**
  - **Pass address of argument using & operator**
  - **Allows you to change actual location in memory**
  - **Arrays are not passed with & because the array name is already a pointer** Note CareFully!
- *** operator**
  - **Used as alias/nickname for variable inside of function**

```
void double( int *number )
 {
  *number = 2 * ( *number );
 }
```

  - **`*number` used as nickname for the variable passed**

Outline

fig07_06.c

```c
/* Fig. 7.6: fig07_06.c
   Cube a variable using call-by-value */
#include <stdio.h>

int cubeByValue( int n ); /* prototype */

int main( void )
{
   int number = 5; /* initialize number */

   printf( "The original value of number is %d", number );

   /* pass number by value to cubeByValue */
   number = cubeByValue( number );

   printf( "\nThe new value of number is %d\n", number );

   return 0; /* indicates successful termination */

} /* end main */

/* calculate and return cube of integer argument */
int cubeByValue( int n )
{
   return n * n * n;   /* cube local variable n and return result */

} /* end function cubeByValue */
```

```
The original value of number is 5
The new value of number is 125
```

Common Programming Error 7.3

Not dereferencing a pointer when it is necessary to do so in order to obtain the value to which the pointer points is a syntax error.

Outline

fig07_07.c

```c
/* Fig. 7.7: fig07_07.c
   Cube a variable using call-by-reference with a pointer argument */

#include <stdio.h>

void cubeByReference( int *nPtr ); /* prototype */

int main( void )
{
   int number = 5; /* initialize number */

   printf( "The original value of number is %d", number );

   /* pass address of number to cubeByReference */
   cubeByReference( &number );

   printf( "\nThe new value of number is %d\n", number );

   return 0; /* indicates successful termination */

} /* end main */

/* calculate cube of *nPtr; modifies variable number in main */
void cubeByReference( int *nPtr )
{
   *nPtr = *nPtr * *nPtr * *nPtr;  /* cube *nPtr */
} /* end function cubeByReference */
```

Function prototype takes a pointer argument

Function **cubeByReference** is passed an address, which can be the value of a pointer variable

In this program, ***nPtr** is **number**, so this statement modifies the value of **number** itself.

```
The original value of number is 5
The new value of number is 125
```

Step 1: Before `main` calls `cubeByValue`:

```
int main( void )
{
   int number = 5;

   number = cubeByValue( number );
}
```

number: 5

```
int cubeByValue( int n )
{
   return n * n * n;
}
```

n: undefined

Step 2: After `cubeByValue` receives the call:

```
int main( void )
{
   int number = 5;

   number = cubeByValue( number );
}
```

number: 5

```
int cubeByValue( int n )
{
   return n * n * n;
}
```

n: 5

Step 3: After `cubeByValue` cubes parameter `n` and before `cubeByValue` returns to `main`:

```
int main( void )
{
   int number = 5;

   number = cubeByValue( number );
}
```

number: 5

```
int cubeByValue( int n )
{
   return n * n * n;
}
```

125

n: 5

Step 4: After `cubeByValue` returns to `main` and before assigning the result to `number`:

```
int main( void )
{
   int number = 5;

   number = cubeByValue( number );
}
```

125

number: 5

```
int cubeByValue( int n )
{
   return n * n * n;
}
```

n: undefined

Step 5: After `main` completes the assignment to `number`:

```
int main( void )
{
   int number = 5;

   number = cubeByValue( number );
}
```

125 125

number: 125

```
int cubeByValue( int n )
{
   return n * n * n;
}
```

n: undefined

Fig. 7.8 | Analysis of a typical call-by-value.

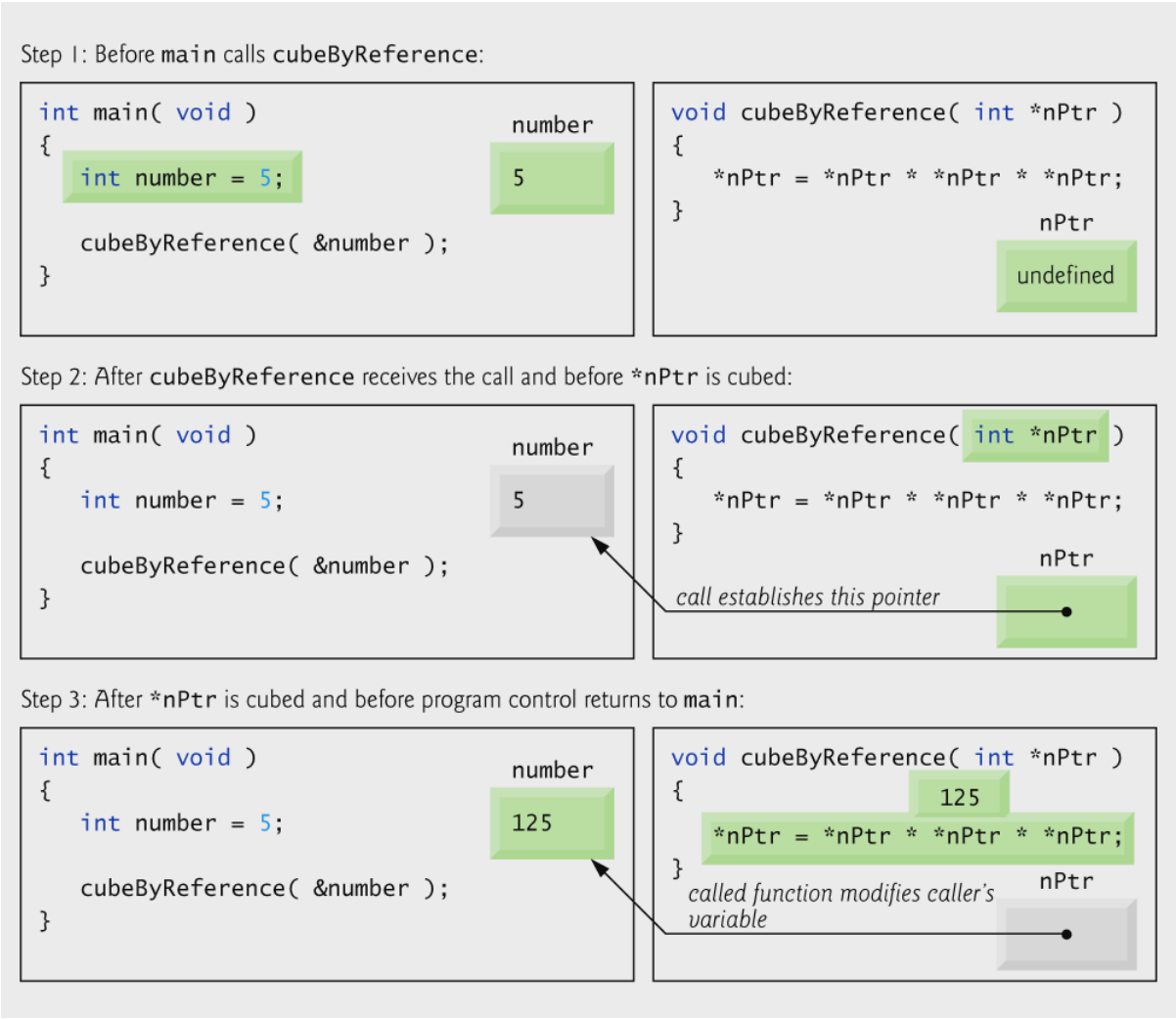


Fig. 7.9 | Analysis of a typical call-by-reference with a pointer argument.

Error-Prevention Tip 7.2

Use call-by-value to pass arguments to a function unless the caller explicitly requires the called function to modify the value of the argument variable in the caller's environment. This prevents accidental modification of the caller's arguments and is another example of the principle of least privilege.

7.5 Using the const Qualifier with Pointers

- const qualifier
  - Variable cannot be changed
  - Use const if function does not need to change a variable
  - Attempting to change a const variable produces an error
- const pointers
  - Point to a constant memory location
  - Must be initialized when defined
  - int *const myPtr = &x;
    - Type int *const – constant pointer to an int
  - const int *myPtr = &x;
    - Modifiable pointer to a const int
  - const int *const Ptr = &x;
    - const pointer to a const int
    - x itself can be changed, but not *Ptr

Software Engineering Observation 7.1

The `const` qualifier can be used to enforce the principle of least privilege. Using the principle of least privilege to properly design software reduces debugging time and improper side effects, making a program easier to modify and maintain.

Portability Tip 7.1

Although `const` is well defined in Standard C, some compilers do not enforce it.

Error-Prevention Tip 7.3

If a variable does not (or should not) change in the body of a function to which it is passed, the variable should be declared `const` to ensure that it is not accidentally modified.

Software Engineering Observation 7.2

Only one value can be altered in a calling function when call-by-value is used. That value must be assigned from the return value of the function. To modify multiple values in a calling function, call-by-reference must be used.

Error-Prevention Tip 7.4

Before using a function, check its function prototype to determine if the function is able to modify the values passed to it.

Common Programming Error 7.4

Being unaware that a function is expecting pointers as arguments for call-by-reference and passing arguments call-by-value. Some compilers take the values assuming they are pointers and dereference the values as pointers. At runtime, memory-access violations or segmentation faults are often generated. Other compilers catch the mismatch in types between arguments and parameters and generate error messages.

Outline

fig07_10.c

(1 of 2)

```
1  /* Fig. 7.10: fig07_10.c
2     Converting lowercase letters to uppercase letters
3     using a non-constant pointer to non-constant data */
4
5  #include <stdio.h>
6  #include <ctype.h>
7
8  void convertToUppercase( char *sPtr ); /* prototype */
9
10 int main( void )
11 {
12    char string[] = "characters and $32.98"; /* initialize char array */
13
14    printf( "The string before conversion is: %s", string );
15    convertToUppercase( string );
16    printf( "\nThe string after conversion is: %s\n", string );
17
18    return 0; /* indicates successful termination */
19
20 } /* end main */
21
```

Both **sPtr** and ***sPtr** are modifiable

Outline

fig07_10.c

(2 of 2)

```
22 /* convert string to uppercase letters */
23 void convertToUppercase( char *sPtr )
24 {
25    while ( *sPtr != '\0' ) { /* current character is not '\0' */
26
27       if ( islower( *sPtr ) ) {    /* if character is lowercase, */
28          *sPtr = toupper( *sPtr ); /* convert to uppercase */
29       } /* end if */
30
31       ++sPtr;  /* move sPtr to the next character */
32    } /* end while */
33
34 } /* end function convertToUppercase */
```

Both **sPtr** and ***sPtr** are modified by the **convertToUppercase** function

```
The string before conversion is: characters and $32.98
The string after conversion is: CHARACTERS AND $32.98
```

Outline

```
1  /* Fig. 7.11: fig07_11.c
2     Printing a string one character at a time using
3     a non-constant pointer to constant data */
4
5  #include <stdio.h>
6
7  void printCharacters( const char *sPtr );
8
9  int main( void )
10 {
11    /* initialize char array */
12    char string[] = "print characters of a string";
13
14    printf( "The string is:\n" );
15    printCharacters( string );
16    printf( "\n" );
17
18    return 0; /* indicates successful termination */
19
20 } /* end main */
21
```

Pointer variable **sPtr** is modifiable, but the data to which it points, ***sPtr**, is not

fig07_11.c

(1 of 2)

Outline

```
22 /* sPtr cannot modify the character to which it points,
23    i.e., sPtr is a "read-only" pointer */
24 void printCharacters( const char *sPtr )
25 {
26    /* loop through entire string */
27    for ( ; *sPtr != '\0'; sPtr++ ) { /* no initialization */
28       printf( "%c", *sPtr );
29    } /* end for */
30
31 } /* end function printCharacters */
```

fig07_11.c

(2 of 2)

sPtr is modified by function **printCharacters**

```
The string is:
print characters of a string
```

Outline

fig07_12.c

```
1  /* Fig. 7.12: fig07_12.c
2     Attempting to modify data through a
3     non-constant pointer to constant data. */
4  #include <stdio.h>
5  void f( const int *xPtr ); /* prototype */
6
7
8  int main( void )
9  {
10    int y;        /* define y */
11
12    f( &y );      /* f attempts illegal modification */
13
14    return 0;     /* indicates successful termination */
15
16 } /* end main */
17
18 /* xPtr cannot be used to modify the
19    value of the variable to which it points */
20 void f( const int *xPtr )
21 {
22    *xPtr = 100;  /* error: cannot modify a const object */
23 } /* end function f */
```

Pointer variable **xPtr** is modifiable, but the data to which it points, ***xPtr**, is not

***xPtr** has the **const** qualifier, so attempting to modify its value causes an error

```
Compiling...
FIG07_12.c
c:\books\2006\chtp5\examples\ch07\fig07_12.c(22) : error C2166: l-value
   specifies const object
Error executing cl.exe.

FIG07_12.exe - 1 error(s), 0 warning(s)
```

Performance Tip 7.1

Pass large objects such as structures using pointers to constant data to obtain the performance benefits of call-by-reference and the security of call-by-value.

Outline

fig07_13.c

```
1  /* Fig. 7.13: fig07_13.c
2     Attempting to modify a constant pointer to non-constant data */
3  #include <stdio.h>
4
5  int main( void )
6  {
7     int x; /* define x */
8     int y; /* define y */
9
10    /* ptr is a constant pointer to an integer that can be modified
11       through ptr, but ptr always points to the same memory location */
12    int * const ptr = &x;
13
14    *ptr = 7; /* allowed: *ptr is not const */
15    ptr = &y; /* error: ptr is const; cannot assign new address */
16
17    return 0; /* indicates successful termination */
18
19 } /* end main */
```

Pointer **ptr** is not modifiable, but the data to which it points, ***ptr**, can be changed

```
Compiling...
FIG07_13.c
c:\books\2006\chtp5\Examples\ch07\FIG07_13.c(15) : error C2166: l-value
   specifies const object
Error executing cl.exe.

FIG07_13.exe - 1 error(s), 0 warning(s)
```

Outline

fig07_14.c

```c
/* Fig. 7.14: fig07_14.c
   Attempting to modify a constant pointer to constant data. */
#include <stdio.h>

int main( void )
{
   int x = 5; /* initialize x */
   int y;     /* define y */

   /* ptr is a constant pointer to a constant integer. ptr always
      points to the same location; the integer at that location
      cannot be modified */
   const int *const ptr = &x;

   printf( "%d\n", *ptr );

   *ptr = 7; /* error: *ptr is const; cannot assign new value */
   ptr = &y; /* error: ptr is const; cannot assign new address */

   return 0; /* indicates successful termination */

} /* end main */
```

Neither pointer **sPtr** nor the data to which it points, ***sPtr**, is modifiable

```
Compiling...
FIG07_14.c
c:\books\2006\chtp5\Examples\ch07\FIG07_14.c(17) : error C2166: l-value
   specifies const object
c:\books\2006\chtp5\Examples\ch07\FIG07_14.c(18) : error C2166: l-value
   specifies const object
Error executing cl.exe.

FIG07_12.exe - 2 error(s), 0 warning(s)
```

7.6 Bubble Sort Using Call-by-Reference

- **Implement bubble sort using pointers**
  - **Swap two elements**
  - **swap function must receive address (using &) of array elements**
    - **Array elements have call-by-value default**
  - **Using pointers and the * operator, swap can switch array elements**
- **Psuedocode**

  Initialize array

  print data in original order

  Call function bubble sort

  print sorted array

  Define bubble sort

Outline

fig07_15.c

(1 of 3)

```c
/* Fig. 7.15: fig07_15.c
   This program puts values into an array, sorts the values into
   ascending order, and prints the resulting array. */
#include <stdio.h>
#define SIZE 10

void bubbleSort( int * const array, const int size ); /* prototype */

int main( void )
{
   /* initialize array a */
   int a[ SIZE ] = { 2, 6, 4, 8, 10, 12, 89, 68, 45, 37 };

   int i; /* counter */

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

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

   bubbleSort( a, SIZE ); /* sort the array */

   printf( "\nData items in ascending order\n" );

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

Outline

fig07_15.c

(2 of 3)

```
31
32    printf( "\n" );
33
34    return 0; /* indicates successful termination */
35
36 } /* end main */
37
38 /* sort an array of integers using bubble sort algorithm */
39 void bubbleSort( int * const array, const int size )
40 {
41    void swap( int *element1Ptr, int *element2Ptr ); /* prototype */
42    int pass; /* pass counter */
43    int j;    /* comparison counter */
44
45    /* loop to control passes */
46    for ( pass = 0; pass < size - 1; pass++ ) {
47
48       /* loop to control comparisons during each pass */
49       for ( j = 0; j < size - 1; j++ ) {
50
51          /* swap adjacent elements if they are out of order */
52          if ( array[ j ] > array[ j + 1 ] ) {
53             swap( &array[ j ], &array[ j + 1 ] );
54          } /* end if */
55
56       } /* end inner for */
57
58    } /* end outer for */
59
60 } /* end function bubbleSort */
```

Outline

```
61
62 /* swap values at memory locations to which element1Ptr and
63    element2Ptr point */
64 void swap( int *element1Ptr, int *element2Ptr )
65 {
66    int hold = *element1Ptr;
67    *element1Ptr = *element2Ptr;
68    *element2Ptr = hold;
69 } /* end function swap */
```

Function **swap** changes the values of the **int**s that the two pointers point to

```
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
```

fig07_15.c

(3 of 3)

Software Engineering Observation 7.3

Placing function prototypes in the definitions of other functions enforces the principle of least privilege by restricting proper function calls to the functions in which the prototypes appear.

Software Engineering Observation 7.4

When passing an array to a function, also pass the size of the array. This helps make the function reusable in many programs.

Software Engineering Observation 7.5

Global variables usually violate the principle of least privilege and can lead to poor software engineering. Global variables should be used only to represent truly shared resources, such as the time of day.

7.7 sizeof Operator

- sizeof
  - Returns size of operand in bytes
  - For arrays: size of 1 element * number of elements
  - if sizeof(int) equals 4 bytes, then

```
int myArray[ 10 ];
printf( "%d", sizeof( myArray ) );
```

    - will print 40
- sizeof can be used with
  - Variable names
  - Type name
  - Constant values

Outline

fig07_16.c

```c
/* Fig. 7.16: fig07_16.c
   Sizeof operator when used on an array name
   returns the number of bytes in the array. */
#include <stdio.h>

size_t getSize( float *ptr ); /* prototype */

int main( void )
{
   float array[ 20 ]; /* create array */

   printf( "The number of bytes in the array is %d"
           "\nThe number of bytes returned by getSize is %d\n",
           sizeof( array ), getSize( array ) );

   return 0; /* indicates successful termination */

} /* end main */

/* return size of ptr */
size_t getSize( float *ptr )
{
   return sizeof( ptr );

} /* end function getSize */
```

floats take up 4 bytes in memory, so 20 **float**s take up 80 bytes

```
The number of bytes in the array is 80
The number of bytes returned by getSize is 4
```

Performance Tip 7.2

`sizeof` is a compile-time operator, so it does not incur any execution-time overhead.

Portability Tip 7.2

The number of bytes used to store a particular data type may vary between systems. When writing programs that depend on data type sizes and that will run on several computer systems, use `sizeof` to determine the number of bytes used to store the data types.

Outline

fig07_17.c

(1 of 2)

```c
/* Fig. 7.17: fig07_17.c
   Demonstrating the sizeof operator */
#include <stdio.h>

int main( void )
{
   char c;
   short s;
   int i;
   long l;
   float f;
   double d;
   long double ld;
   int array[ 20 ];  /* create array of 20 int elements */
   int *ptr = array; /* create pointer to array */

```

Outline

fig07_17.c

(2 of 2)

```
17    printf( "     sizeof c = %d\tsizeof(char)  = %d"
18            "\n     sizeof s = %d\tsizeof(short) = %d"
19            "\n     sizeof i = %d\tsizeof(int) = %d"
20            "\n     sizeof l = %d\tsizeof(long) = %d"
21            "\n     sizeof f = %d\tsizeof(float) = %d"
22            "\n     sizeof d = %d\tsizeof(double) = %d"
23            "\n    sizeof ld = %d\tsizeof(long double) = %d"
24            "\n sizeof array = %d"
25            "\n   sizeof ptr = %d\n",
26          sizeof c, sizeof( char ), sizeof s, sizeof( short ), sizeof i,
27          sizeof( int ), sizeof l, sizeof( long ), sizeof f,
28          sizeof( float ), sizeof d, sizeof( double ), sizeof ld,
29          sizeof( long double ), sizeof array, sizeof ptr );
30
31    return 0; /* indicates successful termination */
32
33 } /* end main */
```

```
     sizeof c = 1       sizeof(char)  = 1
     sizeof s = 2       sizeof(short) = 2
     sizeof i = 4       sizeof(int) = 4
     sizeof l = 4       sizeof(long) = 4
     sizeof f = 4       sizeof(float) = 4
     sizeof d = 8       sizeof(double) = 8
    sizeof ld = 8       sizeof(long double) = 8
sizeof array = 80
  sizeof ptr = 4
```

7.8 Pointer Expressions and Pointer Arithmetic

- **Arithmetic operations can be performed on pointers**
  - **Increment/decrement pointer (++ or --)**
  - **Add an integer to a pointer(+ or += , - or -=)**
  - **Pointers may be subtracted from each other**
  - **Operations meaningless unless performed on an array**

7.8 Pointer Expressions and Pointer Arithmetic

- 5 element `int` array on machine with 4 byte `int`s
  - `vPtr` points to first element `v[ 0 ]`
    - at location 3000 (`vPtr` = 3000)
  - `vPtr += 2;` sets `vPtr` to 3008
    - `vPtr` points to `v[ 2 ]` (incremented by 2), but the machine has 4 byte `int`s, so it points to address 3008

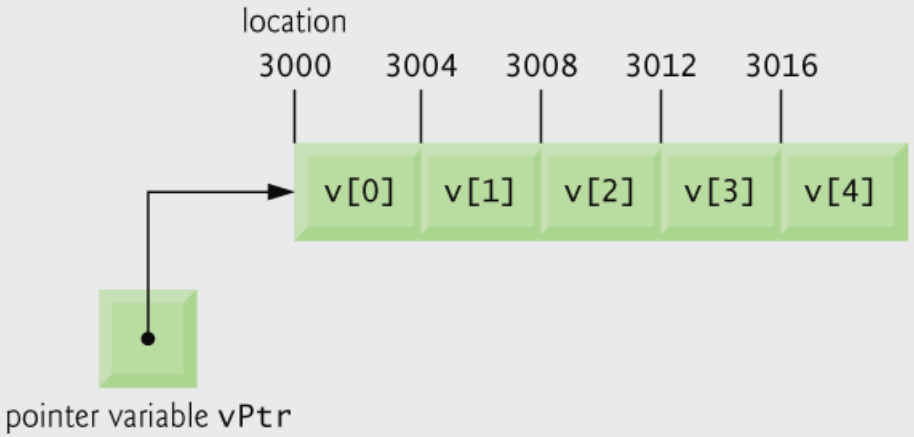


Fig. 7.18 | Array **v** and a pointer variable **vPtr** that points to **v**.

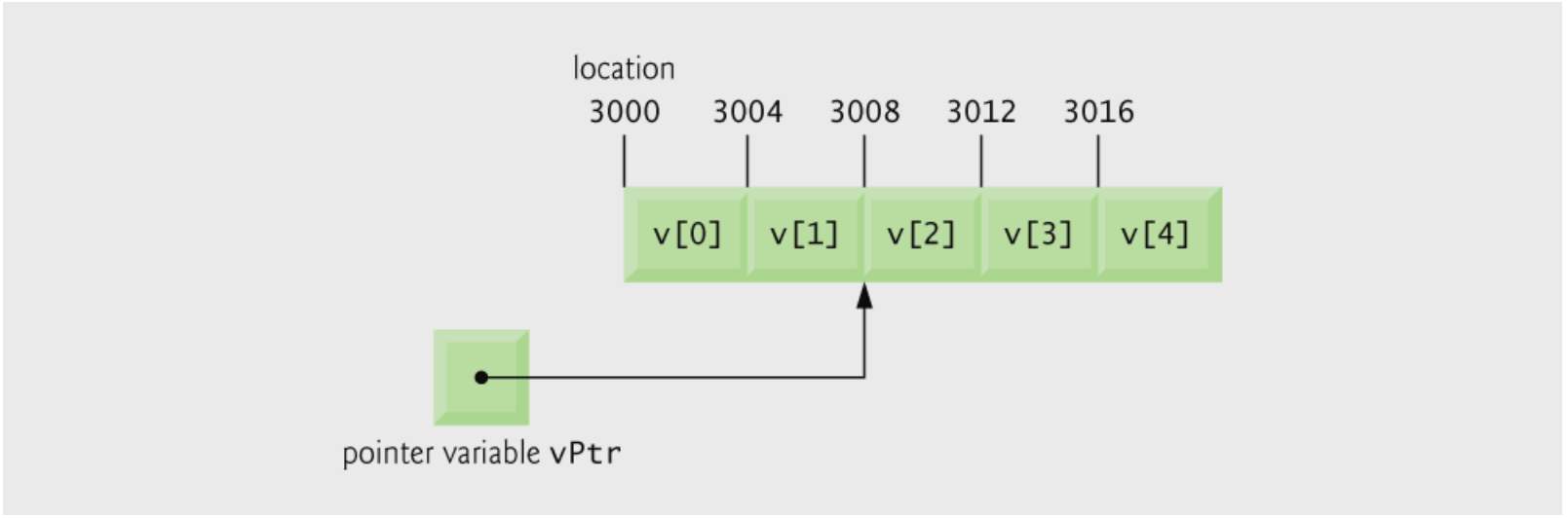


Fig. 7.19 | The pointer **`vPtr`** after pointer arithmetic.

Portability Tip 7.3

Most computers today have 2-byte or 4-byte integers. Some of the newer machines use 8-byte integers. Because the results of pointer arithmetic depend on the size of the objects a pointer points to, pointer arithmetic is machine dependent.

7.8 Pointer Expressions and Pointer Arithmetic

- **Subtracting pointers**
  - **Returns number of elements from one to the other. If**

```
vPtr2 = v[ 2 ];
vPtr = v[ 0 ];
```

  - `vPtr2 - vPtr` **would produce 2**
- **Pointer comparison (<, == , >)**
  - **See which pointer points to the higher numbered array element**
  - **Also, see if a pointer points to** `0`

Common Programming Error 7.5

Using pointer arithmetic on a pointer that does not refer to an element in an array.

Common Programming Error 7.6

Subtracting or comparing two pointers that do not refer to elements in the same array.

Common Programming Error 7.7

Running off either end of an array when using pointer arithmetic.

7.8 Pointer Expressions and Pointer Arithmetic

- **Pointers of the same type can be assigned to each other**
  - **If not the same type, a cast operator must be used**
  - **Exception: pointer to `void` (type `void *`)**
    - **Generic pointer, represents any type**
    - **No casting needed to convert a pointer to `void` pointer**
    - **`void` pointers cannot be dereferenced**

Common Programming Error 7.8

Assigning a pointer of one type to a pointer of another type if neither is of type `void *` is a syntax error.

Common Programming Error 7.9

Dereferencing a `void *` pointer is a syntax error.

7.9 Relationship Between Pointers and Arrays

- **Arrays and pointers closely related**
  - **Array name like a constant pointer**
  - **Pointers can do array subscripting operations**
- **Define an array `b[ 5 ]` and a pointer `bPtr`**
  - **To set them equal to one another use:**

```
bPtr = b;
```

    - **The array name (`b`) is actually the address of first element of the array `b[ 5 ]`**

```
bPtr = &b[ 0 ]
```

    - **Explicitly assigns `bPtr` to address of first element of `b`**

7.9 Relationship Between Pointers and Arrays

- Element `b[ 3 ]`
  - Can be accessed by `*( bPtr + 3 )`

    Where 3 is called the offset. Called pointer/offset notation
  - Can be accessed by `bptr[ 3 ]`

    Called pointer/subscript notation

    `bPtr[ 3 ]` same as `b[ 3 ]`
  - Can be accessed by performing pointer arithmetic on the array itself

    `*( b + 3 )`

Common Programming Error 7.10

Attempting to modify an array name with pointer arithmetic is a syntax error.

Outline

fig07_20.c

(1 of 3)

```
1  /* Fig. 7.20: fig07_20.cpp
2     Using subscripting and pointer notations with arrays */
3
4  #include <stdio.h>
5
6  int main( void )
7  {
8     int b[] = { 10, 20, 30, 40 }; /* initialize array b */
9     int *bPtr = b;                /* set bPtr to point to array b */
10    int i;                        /* counter */
11    int offset;                   /* counter */
12
13    /* output array b using array subscript notation */
14    printf( "Array b printed with:\nArray subscript notation\n" );
15
16    /* loop through array b */
17    for ( i = 0; i < 4; i++ ) {
18       printf( "b[ %d ] = %d\n", i, b[ i ] );
19    } /* end for */
20
21    /* output array b using array name and pointer/offset notation */
22    printf( "\nPointer/offset notation where\n"
23            "the pointer is the array name\n" );
24
25    /* loop through array b */
26    for ( offset = 0; offset < 4; offset++ ) {
27       printf( "*( b + %d ) = %d\n", offset, *( b + offset ) );
28    } /* end for */
29
```

Array subscript notation

Pointer/offset notation

Outline

fig07_20.c

(2 of 3)

```
30    /* output array b using bPtr and array subscript notation */
31    printf( "\nPointer subscript notation\n" );
32
33    /* loop through array b */
34    for ( i = 0; i < 4; i++ ) {
35       printf( "bPtr[ %d ] = %d\n", i, bPtr[ i ] );
36    } /* end for */
37
38    /* output array b using bPtr and pointer/offset notation */
39    printf( "\nPointer/offset notation\n" );
40
41    /* loop through array b */
42    for ( offset = 0; offset < 4; offset++ ) {
43       printf( "*( bPtr + %d ) = %d\n", offset, *( bPtr + offset ) );
44    } /* end for */
45
46    return 0; /* indicates successful termination */
47
48 } /* end main */
```

Pointer subscript notation

Pointer offset notation

```
Array b printed with:
Array subscript notation
b[ 0 ] = 10
b[ 1 ] = 20
b[ 2 ] = 30
b[ 3 ] = 40
```

(continued on next slide…)

(continued from previous slide…)

```
Pointer/offset notation where
the pointer is the array name
*( b + 0 ) = 10
*( b + 1 ) = 20
*( b + 2 ) = 30
*( b + 3 ) = 40

Pointer subscript notation
bPtr[ 0 ] = 10
bPtr[ 1 ] = 20
bPtr[ 2 ] = 30
bPtr[ 3 ] = 40

Pointer/offset notation
*( bPtr + 0 ) = 10
*( bPtr + 1 ) = 20
*( bPtr + 2 ) = 30
*( bPtr + 3 ) = 40
```

Outline

fig07_20.c

(3 of 3)

Outline

fig07_21.c

(1 of 2)

```c
/* Fig. 7.21: fig07_21.c
   Copying a string using array notation and pointer notation. */
#include <stdio.h>

void copy1( char * const s1, const char * const s2 ); /* prototype */
void copy2( char *s1, const char *s2 ); /* prototype */

int main( void )
{
   char string1[ 10 ];           /* create array string1 */
   char *string2 = "Hello";      /* create a pointer to a string */
   char string3[ 10 ];           /* create array string3 */
   char string4[] = "Good Bye"; /* create a pointer to a string */

   copy1( string1, string2 );
   printf( "string1 = %s\n", string1 );

   copy2( string3, string4 );
   printf( "string3 = %s\n", string3 );

   return 0; /* indicates successful termination */

} /* end main */

```

Outline

fig07_21.c

(2 of 2)

```
25 /* copy s2 to s1 using array notation */
26 void copy1( char * const s1, const char * const s2 )
27 {
28    int i; /* counter */
29
30    /* loop through strings */
31    for ( i = 0; ( s1[ i ] = s2[ i ] ) != '\0'; i++ ) {
32       ; /* do nothing in body */
33    } /* end for */
34
35 } /* end function copy1 */
36
37 /* copy s2 to s1 using pointer notation */
38 void copy2( char *s1, const char *s2 )
39 {
40    /* loop through strings */
41    for ( ; ( *s1 = *s2 ) != '\0'; s1++, s2++ ) {
42       ; /* do nothing in body */
43    } /* end for */
44
45 } /* end function copy2 */
```

Condition of **for** loop actually performs an action

```
string1 = Hello
string3 = Good Bye
```

7.10 Arrays of Pointers

- **Arrays can contain pointers**
- **For example: an array of strings**

```
char *suit[ 4 ] = { "Hearts", "Diamonds",
   "Clubs", "Spades" };
```

  - **Strings are pointers to the first character**
  - **`char *` – each element of `suit` is a pointer to a `char`**
  - **The strings are not actually stored in the array `suit`, only pointers to the strings are stored**

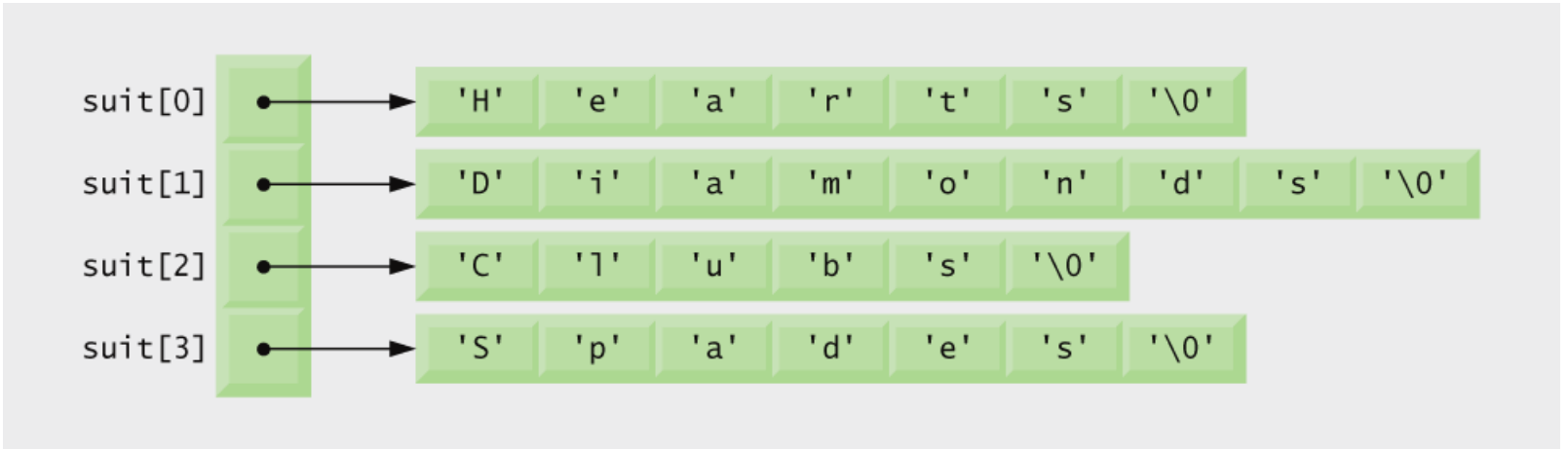


Fig. 7.22 | Graphical representation of the **`suit`** array.

7.11 Case Study: Card Shuffling and Dealing Simulation

- **Card shuffling program**
  - **Use array of pointers to strings**
  - **Use double subscripted array (suit, face)**
  - **The numbers 1-52 go into the array**
    - **Representing the order in which the cards are dealt**

Performance Tip 7.3

Sometimes an algorithm that emerges in a "natural" way can contain subtle performance problems, such as indefinite postponement. Seek algorithms that avoid indefinite postponement.

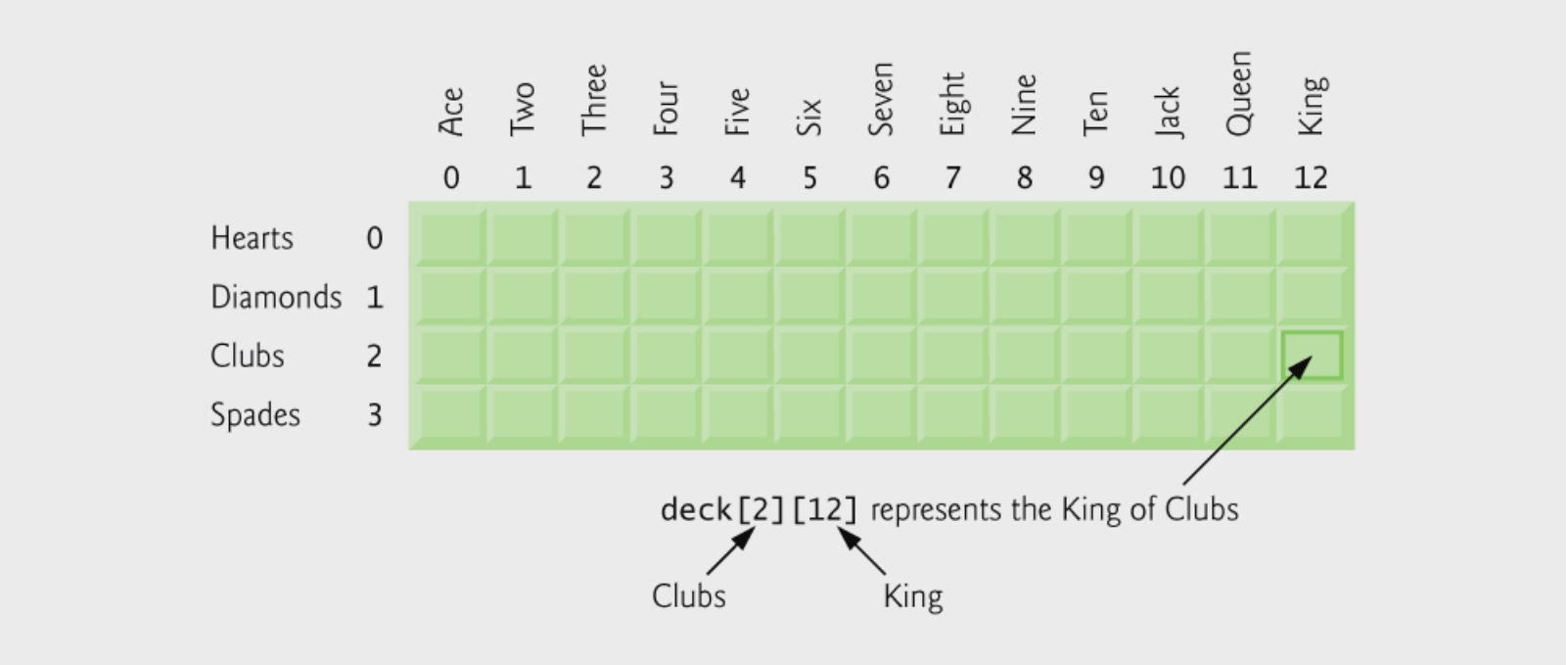


Fig. 7.23 | Double-subscripted array representation of a deck of cards.

7.11 Case Study: Card Shuffling and Dealing Simulation

- **Pseudocode**
  - **Top level:**

    Shuffle and deal 52 cards
  - **First refinement:**

    Initialize the suit array

    Initialize the face array

    Initialize the deck array

    Shuffle the deck

    Deal 52 cards

7.11 Case Study: Card Shuffling and Dealing Simulation

- **Second refinement**
  - **Convert *shuffle the deck* to**

    For each of the 52 cards

    Place card number in randomly selected unoccupied slot of deck
  - **Convert *deal 52 cards* to**

    For each of the 52 cards

    Find card number in deck array and print face and suit of card

7.11 Case Study: Card Shuffling and Dealing Simulation

- **Third refinement**
  - **Convert *shuffle the deck* to**

    Choose slot of deck randomly

    While chosen slot of deck has been previously chosen
    Choose slot of deck randomly

    Place card number in chosen slot of deck
  - **Convert *deal 52 cards* to**

    For each slot of the deck array
    If slot contains card number
    Print the face and suit of the card

Outline

fig07_24.c

(1 of 4)

```
1  /* Fig. 7.24: fig07_24.c
2     Card shuffling dealing program */
3  #include <stdio.h>
4  #include <stdlib.h>
5  #include <time.h>
6
7  /* prototypes */
8  void shuffle( int wDeck[][ 13 ] );
9  void deal( const int wDeck[][ 13 ], const char *wFace[],
10            const char *wSuit[] );
11
12 int main( void )
13 {
14    /* initialize suit array */
15    const char *suit[ 4 ] = { "Hearts", "Diamonds", "Clubs", "Spades" };
16
17    /* initialize face array */
18    const char *face[ 13 ] =
19       { "Ace", "Deuce", "Three", "Four",
20         "Five", "Six", "Seven", "Eight",
21         "Nine", "Ten", "Jack", "Queen", "King" };
22
```

suit and **face** arrays are arrays of pointers

Outline

fig07_24.c

(2 of 4)

```
23    /* initialize deck array */
24    int deck[ 4 ][ 13 ] = { 0 };
25
26    srand( time( 0 ) ); /* seed random-number generator */
27
28    shuffle( deck );
29    deal( deck, face, suit );
30
31    return 0; /* indicates successful termination */
32
33 } /* end main */
34
35 /* shuffle cards in deck */
36 void shuffle( int wDeck[][ 13 ] )
37 {
38    int row;    /* row number */
39    int column; /* column number */
40    int card;   /* counter */
41
42    /* for each of the 52 cards, choose slot of deck randomly */
43    for ( card = 1; card <= 52; card++ ) {
44
45       /* choose new random location until unoccupied slot found */
46       do {
47          row = rand() % 4;
48          column = rand() % 13;
49       } while( wDeck[ row ][ column ] != 0 ); /* end do...while */
50
```

do…while loop selects a random spot for each card

Outline

fig07_24.c

(3 of 4)

```
51       /* place card number in chosen slot of deck */
52       wDeck[ row ][ column ] = card;
53    } /* end for */
54
55 } /* end function shuffle */
56
57 /* deal cards in deck */
58 void deal( const int wDeck[][ 13 ], const char *wFace[],
59            const char *wSuit[] )
60 {
61    int card;   /* card counter */
62    int row;    /* row counter */
63    int column; /* column counter */
64
65    /* deal each of the 52 cards */
66    for ( card = 1; card <= 52; card++ ) {
67       /* loop through rows of wDeck */
68
69       for ( row = 0; row <= 3; row++ ) {
70
71          /* loop through columns of wDeck for current row */
72          for ( column = 0; column <= 12; column++ ) {
```

```
73
74             /* if slot contains current card, display card */
75             if ( wDeck[ row ][ column ] == card ) {
76                printf( "%5s of %-8s%c", wFace[ column ], wSuit[ row ],
77                   card % 2 == 0 ? '\n' : '\t' );
78             } /* end if */
79
80          } /* end for */
81
82       } /* end for */
83
84    } /* end for */
85
86 } /* end function deal */
```

Outline

fig07_24.c

(4 of 4)

Outline

```
Nine of Hearts          Five of Clubs
Queen of Spades         Three of Spades
Queen of Hearts           Ace of Clubs
 King of Hearts           Six of Spades
 Jack of Diamonds        Five of Spades
Seven of Hearts          King of Clubs
Three of Clubs          Eight of Hearts
Three of Diamonds        Four of Diamonds
Queen of Diamonds        Five of Diamonds
  Six of Diamonds        Five of Hearts
  Ace of Spades           Six of Hearts
 Nine of Diamonds       Queen of Clubs
Eight of Spades          Nine of Clubs
Deuce of Clubs            Six of Clubs
Deuce of Spades          Jack of Clubs
 Four of Clubs          Eight of Clubs
 Four of Spades         Seven of Spades
Seven of Diamonds       Seven of Clubs
 King of Spades           Ten of Diamonds
 Jack of Hearts           Ace of Hearts
 Jack of Spades           Ten of Clubs
Eight of Diamonds       Deuce of Diamonds
  Ace of Diamonds         Nine of Spades
 Four of Hearts         Deuce of Hearts
 King of Diamonds         Ten of Spades
Three of Hearts           Ten of Hearts
```

7.12 Pointers to Functions

- **Pointer to function**
  - **Contains address of function**
  - **Similar to how array name is address of first element**
  - **Function name is starting address of code that defines function**
- **Function pointers can be**
  - **Passed to functions**
  - **Stored in arrays**
  - **Assigned to other function pointers**

7.12 Pointers to Functions

- **Example: bubblesort**
  - Function `bubble` takes a function pointer
    - `bubble` calls this helper function
    - this determines ascending or descending sorting
  - The argument in `bubblesort` for the function pointer:

```
int ( *compare )( int a, int b )
```

    tells `bubblesort` to expect a pointer to a function that takes two `int`s and returns an `int`
  - If the parentheses were left out:

```
int *compare( int a, int b )
```

    - Defines a function that receives two integers and returns a pointer to a `int`

Outline

fig07_26.c

(1 of 4)

```c
/* Fig. 7.26: fig07_26.c
   Multipurpose sorting program using function pointers */
#include <stdio.h>
#define SIZE 10

/* prototypes */
void bubble( int work[], const int size, int (*compare)( int a, int b ) );
int ascending( int a, int b );
int descending( int a, int b );

int main( void )
{
   int order;   /* 1 for ascending order or 2 for descending order */
   int counter; /* counter */

   /* initialize array a */
   int a[ SIZE ] = { 2, 6, 4, 8, 10, 12, 89, 68, 45, 37 };

   printf( "Enter 1 to sort in ascending order,\n"
           "Enter 2 to sort in descending order: " );
   scanf( "%d",  &order );

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

   /* output original array */
   for ( counter = 0; counter < SIZE; counter++ ) {
      printf( "%5d", a[ counter ] );
   } /* end for */

```

bubble function takes a function pointer as an argument

Outline

fig07_26.c

(2 of 4)

```
30    /* sort array in ascending order; pass function ascending as an
31       argument to specify ascending sorting order */
32    if ( order == 1 ) {
33       bubble( a, SIZE, ascending );
34       printf( "\nData items in ascending order\n" );
35    } /* end if */
36    else { /* pass function descending */
37       bubble( a, SIZE, descending );
38       printf( "\nData items in descending order\n" );
39    } /* end else */
40
41    /* output sorted array */
42    for ( counter = 0; counter < SIZE; counter++ ) {
43       printf( "%5d", a[ counter ] );
44    } /* end for */
45
46    printf( "\n" );
47
48    return 0; /* indicates successful termination */
49
50 } /* end main */
51
```

depending on the user's choice, the **bubble** function uses either the **ascending** or **descending** function to sort the array

Outline

fig07_26.c

(3 of 4)

```
52 /* multipurpose bubble sort; parameter compare is a pointer to
53    the comparison function that determines sorting order */
54 void bubble( int work[], const int size, int (*compare)( int a, int b ) )
55 {
56    int pass;  /* pass counter */
57    int count; /* comparison counter */
58
59    void swap( int *element1Ptr, int *element2ptr ); /* prototype */
60
61    /* loop to control passes */
62    for ( pass = 1; pass < size; pass++ ) {
63
64       /* loop to control number of comparisons per pass */
65       for ( count = 0; count < size - 1; count++ ) {
66
67          /* if adjacent elements are out of order, swap them */
68          if ( (*compare)( work[ count ], work[ count + 1 ] ) ) {
69             swap( &work[ count ], &work[ count + 1 ] );
70          } /* end if */
71
72       } /* end for */
73
74    } /* end for */
75
76 } /* end function bubble */
77
```

Note that what the program considers "out of order" is dependent on the function pointer that was passed to the **bubble** function

Outline

fig07_26.c

(4 of 4)

```
78 /* swap values at memory locations to which element1Ptr and
79    element2Ptr point */
80 void swap( int *element1Ptr, int *element2Ptr )
81 {
82    int hold; /* temporary holding variable */
83
84    hold = *element1Ptr;
85    *element1Ptr = *element2Ptr;
86    *element2Ptr = hold;
87 } /* end function swap */
88
89 /* determine whether elements are out of order for an ascending
90    order sort */
91 int ascending( int a, int b )
92 {
93    return b < a; /* swap if b is less than a */
94
95 } /* end function ascending */
96
97 /* determine whether elements are out of order for a descending
98    order sort */
99 int descending( int a, int b )
100 {
101    return b > a; /* swap if b is greater than a */
102
103 } /* end function descending */
```

Passing the **bubble** function **ascending** will point the program here

Passing the **bubble** function **descending** will point the program here

Outline

```
Enter 1 to sort in ascending order,
Enter 2 to sort in descending order: 1

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
```

```
Enter 1 to sort in ascending order,
Enter 2 to sort in descending order: 2

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

Outline

fig07_28.c

(1 of 3)

```c
/* Fig. 7.28: fig07_28.c
   Demonstrating an array of pointers to functions */
#include <stdio.h>

/* prototypes */
void function1( int a );
void function2( int b );
void function3( int c );

int main( void )
{
   /* initialize array of 3 pointers to functions that each take an
      int argument and return void */
   void (*f[ 3 ])( int ) = { function1, function2, function3 };

   int choice; /* variable to hold user's choice */

   printf( "Enter a number between 0 and 2, 3 to end: " );
   scanf( "%d", &choice );

```

Array of pointers to functions

Outline

```
21    /* process user's choice */
22    while ( choice >= 0 && choice < 3 ) {
23
24       /* invoke function at location choice in array f and pass
25          choice as an argument */
26       (*f[ choice ])( choice );
27
28       printf( "Enter a number between 0 and 2, 3 to end: " );
29       scanf( "%d", &choice );
30    } /* end while */
31
32    printf( "Program execution completed.\n" );
33
34    return 0; /* indicates successful termination */
35
36 } /* end main */
37
38 void function1( int a )
39 {
40    printf( "You entered %d so function1 was called\n\n", a );
41 } /* end function1 */
42
43 void function2( int b )
44 {
45    printf( "You entered %d so function2 was called\n\n", b );
46 } /* end function2 */
```

Function called is dependent on user's choice

fig07_28.c

(2 of 3)

Outline

```
47
48 void function3( int c )
49 {
50    printf( "You entered %d so function3 was called\n\n", c );
51 } /* end function3 */
```

```
Enter a number between 0 and 2, 3 to end: 0
You entered 0 so function1 was called

Enter a number between 0 and 2, 3 to end: 1
You entered 1 so function2 was called

Enter a number between 0 and 2, 3 to end: 2
You entered 2 so function3 was called

Enter a number between 0 and 2, 3 to end: 3
Program execution completed.
```

fig07_28.c

(3 of 3)