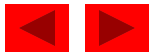
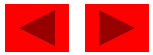
Chapter 7 - Pointers

Outline



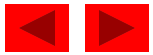
Objectives

- In this chapter, you will learn:
  - To be able to use pointers.
  - To be able to use pointers to pass arguments to functions using call by reference.
  - To understand the close relationships among pointers, arrays and strings.
  - To understand the use of pointers to functions.
  - To be able to define and use arrays of strings.



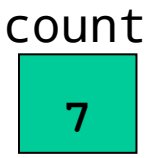
7.1 Introduction

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

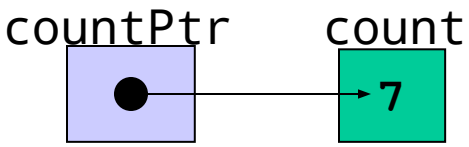


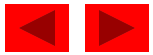
7.2 Pointer Variable Definitions and Initialization

- 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





7.2 Pointer Variable Definitions and Initialization

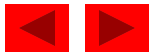
- Pointer definitions
  - `*` used with pointer variables

    ```
    int *myPtr;
    ```

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

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

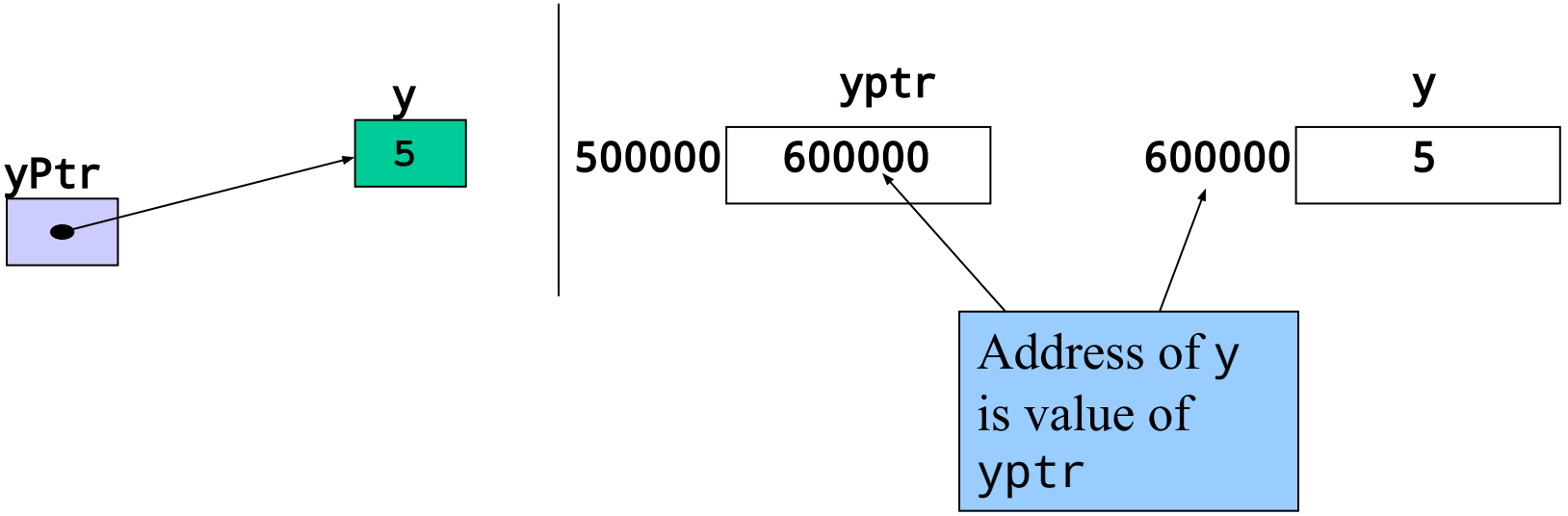
  - Can define pointers to any data type
  - Initialize pointers to `0`, `NULL`, or an address
    - `0` or `NULL` – points to nothing (`NULL` preferred)

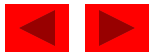


7.3 Pointer Operators

- & (address operator)
  - Returns address of operand

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



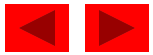


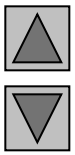
7.3 Pointer Operators

- * (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 */
```

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





Outline

fig07_04.c

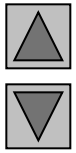
```
1  /* Fig. 7.4: fig07_04.c
2     Using the & and * operators */
3  #include <stdio.h>
4
5  int main()
6  {
7     int a;        /* a is an integer */
8     int *aPtr;    /* aPtr is a pointer to an integer */
9
10    a = 7;
11    aPtr = &a;    /* aPtr set to address of a */
12
13    printf( "The address 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 */
```

The address of a is the value of aPtr.

The * operator returns an alias to what its operand points to. aPtr points to a, so *aPtr returns a.

Notice how * and & are inverses

```
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
```



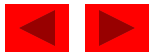
Outline

Program Output

7.3 Pointer Operators

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.

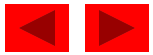


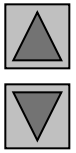
7.4 Calling Functions by Reference

- 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
- * 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



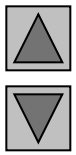


Outline

fig07_06.c

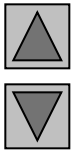
```c
/* Fig. 7.6: fig07_06.c
   Cube a variable using call-by-value */
#include <stdio.h>

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

int main()
{
   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
```



Outline

Program Output



Outline

fig07_07.c

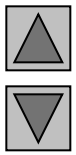
```
1  /* Fig. 7.7: fig07_07.c
2     Cube a variable using call-by-reference with a pointer argument */
3
4  #include <stdio.h>
5
6  void cubeByReference( int *nPtr ); /* prototype */
7
8  int main()
9  {
10    int number = 5; /* initialize number */
11
12    printf( "The original value of number is %d", number );
13
14    /* pass address of number to cubeByReference */
15    cubeByReference( &number );
16
17    printf( "\nThe new value of number is %d\n", number );
18
19    return 0; /* indicates successful termination */
20
21 } /* end main */
22
23 /* calculate cube of *nPtr; modifies variable number in main */
24 void cubeByReference( int *nPtr )
25 {
26    *nPtr = *nPtr * *nPtr * *nPtr;  /* cube *nPtr */
27 } /* end function cubeByReference */
```

Notice that the function prototype takes a pointer to an integer.

Notice how the address of `number` is given - `cubeByReference` expects a pointer (an address of a variable).

Inside `cubeByReference`, `*nPtr` is used (`*nPtr` is `number`).

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



Outline

Program Output

Before `main` calls `cubeByValue`:

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

   number=cubeByValue(number);
}
```

number: 5

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

n: undefined

After `cubeByValue` receives the call:

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

   number = cubeByValue( number );
}
```

number: 5

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

n: 5

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

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

   number = cubeByValue( number );
}
```

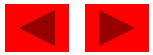
number: 5

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

125

n: 5

Fig. 7.8 Analysis of a typical call-by-value. (Part 1 of 2.)



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

```
int main()
{
   int number =  5;
                          125
      number = cubeByValue( number );
}
```

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

number: 5

n: undefined

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

```
int main()
{
   int number =  5;
     125                  125
   number = cubeByValue( number );
}
```

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

number: 125

n: undefined

Fig. 7.8 Analysis of a typical call-by-value. (Part 2 of 2.)

Before `main` calls `cubeByReference`:

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

   cubeByReference( &number );
}
```

number: 5

```
void cubeByReference( int *nPtr )
{
   *nPtr = *nPtr * *nPtr * *nPtr;
}
```

nPtr: undefined

After `cubeByReference` receives the call and before `*nPtr` is cubed:

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

   cubeByReference( &number );
}
```

number: 5

```
void cubeByReference( int *nPtr )
{
   *nPtr = *nPtr * *nPtr * *nPtr;
}
```

nPtr

call establishes this pointer

After `*nPtr` is cubed and before program control returns to `main`:

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

   cubeByReference( &number );
}
```

number: 12 5

```
void cubeByReference( int *nPtr )
{
   *nPtr = *nPtr * *nPtr * *nPtr;
}
```

125

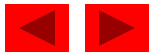
nPtr

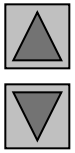
called function modifies caller's variable

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

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;
    - Regular pointer to a const int
  - const int *const Ptr = &x;
    - const pointer to a const int
    - x can be changed, but not *Ptr

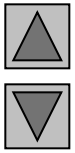




Outline

fig07_10.c (Part 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()
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
```



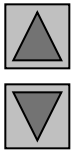
Outline

```
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 */
```

fig07_10.c (Part 2 of 2)

Program Output

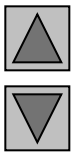
```
The string before conversion is: characters and $32.98
The string after conversion is: CHARACTERS AND $32.98
```



Outline

fig07_11.c (Part 1 of 2)

```
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()
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
```



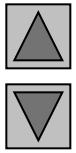
Outline

```
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 (Part 2 of 2)

Program Output

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

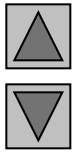


Outline

fig07_12.c

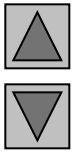
```
1  /* Fig. 7.12: fig07_12.c
2     Attempting to modify data through a
3     non-constant pointer to constant data. */
4  #include <stdio.h>
5
6  void f( const int *xPtr ); /* prototype */
7
8  int main()
9  {
10    int y;        /* define y */
11
12    f( &y );      /* f attempts illegal modification */
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 */
```

```
Compiling...
FIG07_12.c
d:\books\2003\chtp4\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)
```



Outline

Program Output



Outline

fig07_13.c

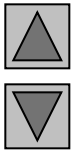
```c
/* Fig. 7.13: fig07_13.c
   Attempting to modify a constant pointer to non-constant data */
#include <stdio.h>

int main()
{
   int x; /* define x */
   int y; /* define y */

   /* ptr is a constant pointer to an integer that can be modified
      through ptr, but ptr always points to the same memory location */
   int * const ptr = &x;

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

   return 0; /* indicates successful termination */

} /* end main */
```

Changing *ptr is allowed – x is not a constant.

Changing ptr is an error – ptr is a constant pointer.

Program Output

```
Compiling...
FIG07_13.c
D:\books\2003\chtp4\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)
```

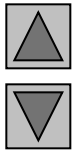


Outline

fig07_14.c

```
1  /* Fig. 7.14: fig07_14.c
2     Attempting to modify a constant pointer to constant data. */
3  #include <stdio.h>
4
5  int main()
6  {
7     int x = 5; /* initialize x */
8     int y;     /* define y */
9
10    /* ptr is a constant pointer to a constant integer. ptr always
11       points to the same location; the integer at that location
12       cannot be modified */
13    const int *const ptr = &x;
14
15    printf( "%d\n", *ptr );
16
17    *ptr = 7; /* error: *ptr is const; cannot assign new value */
18    ptr = &y; /* error: ptr is const; cannot assign new address */
19
20    return 0; /* indicates successful termination */
21
22 } /* end main */
```

```
Compiling...
FIG07_14.c
D:\books\2003\chtp4\Examples\ch07\FIG07_14.c(17) : error C2166: l-value
   specifies const object
D:\books\2003\chtp4\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)
```



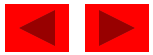
Outline

Program Output

7.6 Bubble Sort Using Call-by-reference

- Implement bubblesort 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 bubblesort
print sorted array
Define bubblesort

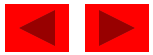


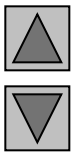
7.6 Bubble Sort Using Call-by-reference

- `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



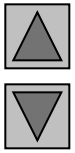


Outline

fig07_15.c (Part 1 of 3)

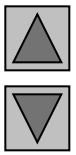
```
1  /* Fig. 7.15: fig07_15.c
2     This program puts values into an array, sorts the values into
3     ascending order, and prints the resulting array. */
4  #include <stdio.h>
5  #define SIZE 10
6
7  void bubbleSort( int *array, const int size ); /* prototype */
8
9  int main()
10 {
11    /* initialize array a */
12    int a[ SIZE ] = { 2, 6, 4, 8, 10, 12, 89, 68, 45, 37 };
13
14    int i; /* counter */
15
16    printf( "Data items in original order\n" );
17
18    /* loop through array a */
19    for ( i = 0; i < SIZE; i++ ) {
20       printf( "%4d", a[ i ] );
21    } /* end for */
22
23    bubbleSort( a, SIZE ); /* sort the array */
24
25    printf( "\nData items in ascending order\n" );
26
```

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



Outline

fig07_15.c (Part 2 of 3)



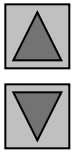
Outline

fig07_15.c (Part 3 of 3)

```
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 */
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 */
```

Program Output

```
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
```



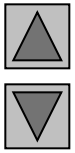
Outline

fig07_16.c

```
1  /* Fig. 7.16: fig07_16.c
2     Sizeof operator when used on an array name
3     returns the number of bytes in the array. */
4  #include <stdio.h>
5
6  size_t getSize( float *ptr ); /* prototype */
7
8  int main()
9  {
10    float array[ 20 ]; /* create array */
11
12    printf( "The number of bytes in the array is %d"
13            "\nThe number of bytes returned by getSize is %d\n",
14            sizeof( array ), getSize( array ) );
15
16    return 0; /* indicates successful termination */
17
18 } /* end main */
19
20 /* return size of ptr */
21 size_t getSize( float *ptr )
22 {
23    return sizeof( ptr );
24
25 } /* end function getSize */
```

Program Output

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



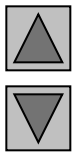
Outline

fig07_17.c (Part 1 of 2)

```
1  /* Fig. 7.17: fig07_17.c
2     Demonstrating the sizeof operator */
3  #include <stdio.h>
4
5  int main()
6  {
7     char c;           /* define c */
8     short s;          /* define s */
9     int i;            /* define i */
10    long l;           /* define l */
11    float f;          /* define f */
12    double d;         /* define d */
13    long double ld;   /* define ld */
14    int array[ 20 ];  /* initialize array */
15    int *ptr = array; /* create pointer to array */
16
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            "\nsizeof array = %d"
25            "\n   sizeof ptr = %d\n",
```

```
26          sizeof c, sizeof( char ), sizeof s,
27          sizeof( short ), sizeof i, sizeof( int ),
28          sizeof l, sizeof( long ), sizeof f,
29          sizeof( float ), sizeof d, sizeof( double ),
30          sizeof ld, sizeof( long double ),
31          sizeof array, sizeof ptr );
32
33    return 0; /* indicates successful termination */
34
35 } /* 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
```



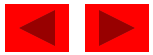
Outline

fig07_17.c (Part 2 of 2)

Program Output

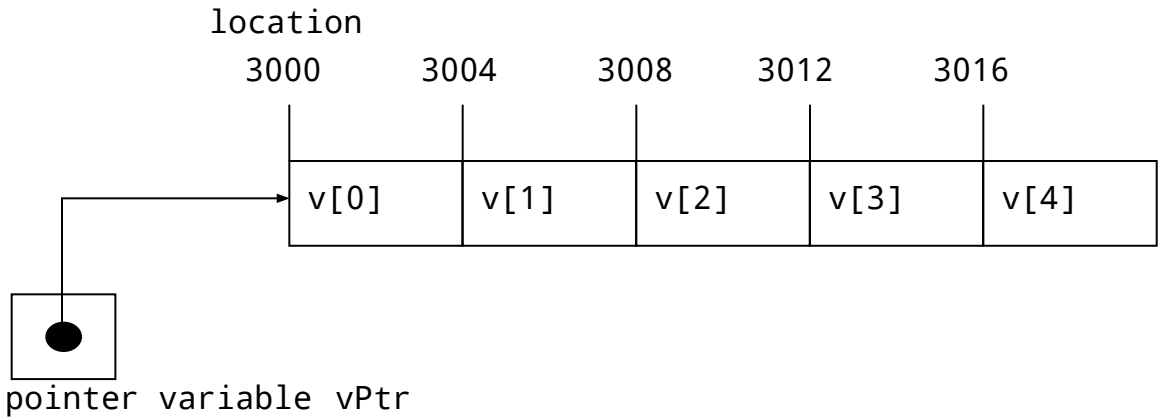
7.7 Pointer Expressions and Pointer Arithmetic

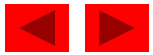
- Arithmetic operations can be performed on pointers
  - Increment/decrement pointer (`++` or `--`)
  - Add an integer to a pointer(`+` or `+=` , `-` or `-=`)
  - Pointers may be subtracted from each other
  - Operations meaningless unless performed on an array



7.7 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`



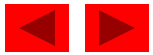


7.7 Pointer Expressions and Pointer Arithmetic

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

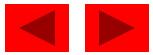
```
vPtr2 = v[ 2 ];
vPtr = v[ 0 ];
```

  - `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`



7.7 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



7.8 The Relationship Between Pointers and Arrays

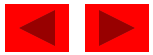
- Arrays and pointers closely related
  - Array name like a constant pointer
  - Pointers can do array subscripting operations
- Define an array `b[ 5 ]` and a pointer `bPtr`
  - To set them equal to one another use:

```
bPtr = b;
```

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

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

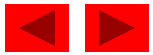
    - Explicitly assigns `bPtr` to address of first element of `b`

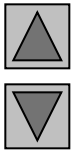


7.8 The Relationship Between Pointers and Arrays

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

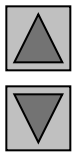




Outline

fig07_20.c (Part 1 of 2)

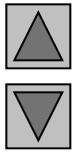
```
1  /* Fig. 7.20: fig07_20.cpp
2     Using subscripting and pointer notations with arrays */
3
4  #include <stdio.h>
5
6  int main()
7  {
8     int b[] = { 10, 20, 30, 40 }; /* initialize array b */
9     int *bPtr = b;                /* set bPtr to point to array b */
10    int i;                        /* 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
```



Outline

fig07_20.c (Part 2 of 2)

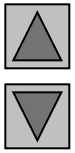
```
25    /* loop through array b */
26    for ( offset = 0; offset < 4; offset++ ) {
27       printf( "*( b + %d ) = %d\n", offset, *( b + offset ) );
28    } /* end for */
29
30    /* output array b using bPtr and array subscript notation */
31    printf( "\nPointer subscript notation\n" );
32
33    /* 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 */
```



Outline

Program Output

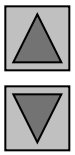
```
Array b printed with:
Array subscript notation
b[ 0 ] = 10
b[ 1 ] = 20
b[ 2 ] = 30
b[ 3 ] = 40

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_21.c (Part 1 of 2)

```
1  /* Fig. 7.21: fig07_21.c
2     Copying a string using array notation and pointer notation. */
3  #include <stdio.h>
4
5  void copy1( char *s1, const char *s2 ); /* prototype */
6  void copy2( char *s1, const char *s2 ); /* prototype */
7
8  int main()
9  {
10    char string1[ 10 ];           /* create array string1 */
11    char *string2 = "Hello";      /* create a pointer to a string */
12    char string3[ 10 ];           /* create array string3 */
13    char string4[] = "Good Bye"; /* create a pointer to a string */
14
15    copy1( string1, string2 );
16    printf( "string1 = %s\n", string1 );
17
18    copy2( string3, string4 );
19    printf( "string3 = %s\n", string3 );
20
21    return 0; /* indicates successful termination */
22
23 } /* end main */
24
```



Outline

fig07_21.c (Part 2 of 2)

```
25 /* copy s2 to s1 using array notation */
26 void copy1( char *s1, const char *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 */
```

Program Output

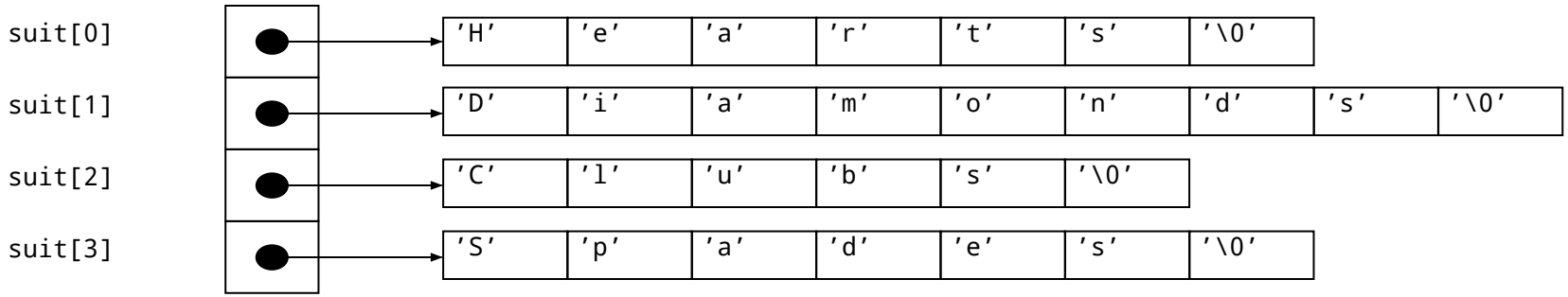
```
string1 = Hello
string3 = Good Bye
```

7.9 Arrays of Pointers

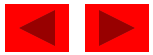
- Arrays can contain pointers
- For example: an array of strings

```
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

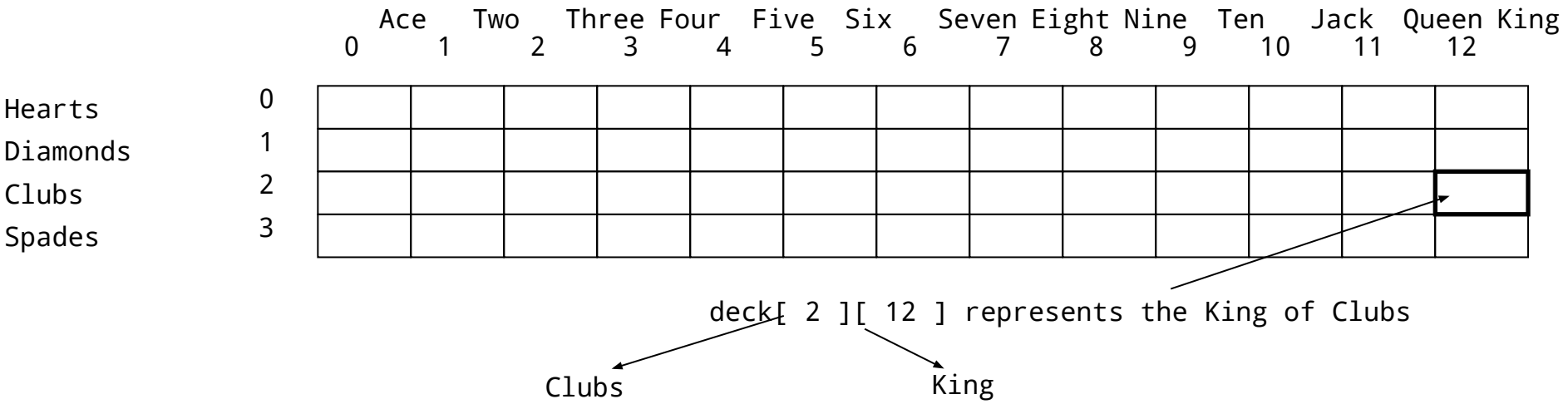


  - `suit` array has a fixed size, but strings can be of any size

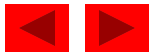


7.10 Case Study: A Card Shuffling and Dealing Simulation

- Card shuffling program
  - Use array of pointers to strings
  - Use double scripted array (suit, face)



  - The numbers 1-52 go into the array
    - Representing the order in which the cards are dealt



7.10 Case Study: A Card Shuffling and Dealing Simulation

- Pseudocode
  - Top level:

    Shuffle and deal 52 cards
  - First refinement:

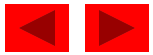
    Initialize the suit array

    Initialize the face array

    Initialize the deck array

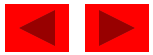
    Shuffle the deck

    Deal 52 cards



7.10 Case Study: A 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



7.10 Case Study: A 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

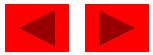
    Choose slot of deck randomly

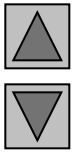
    Place card number in chosen slot of deck
  - Convert *deal 52 cards* to

    For each slot of the deck array

    If slot contains card number

    Print the face and suit of the card

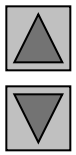




Outline

fig07_24.c (Part 1 of 4)

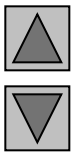
```
1  /* Fig. 7.24: fig07_24.c
2     Card shuffling dealing program */
3  #include <stdio.h>
4  #include <stdlib.h>
5  #include <time.h>
6
7  /* prototypes */
8  void shuffle( int wDeck[][ 13 ] );
9  void deal( const int wDeck[][ 13 ], const char *wFace[],
10            const char *wSuit[] );
11
12 int main()
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
23    /* initialize deck array */
24    int deck[ 4 ][ 13 ] = { 0 };
25
```



Outline

fig07_24.c (Part 2 of 4)

```
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
```

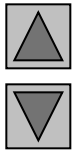


Outline

fig07_24.c (Part 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
68       /* loop through rows of wDeck */
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 ) {
```

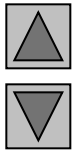
```
76                printf( "%5s of %-8s%c", wFace[ column ], wSuit[ row ],
77                        card % 2 == 0 ? '\n' : '\t' );
78             } /* end if */
79
80          } /* end for */
81
82       } /* end for */
83
84    } /* end for */
85
86 } /* end function deal */
```



Outline

fig07_24.c (Part 4 of 4)

```
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
```

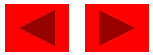


Outline

Program Output

7.11 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



7.11 Pointers to Functions

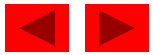
- Example: bubblesort
  - Function `bubble` takes a function pointer
    - `bubble` calls this helper function
    - this determines ascending or descending sorting
  - The argument in `bubblesort` for the function pointer:

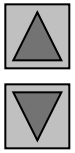
```
int ( *compare )( int a, int b )
```

    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`



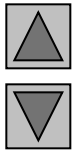


Outline

fig07_26.c (Part 1 of 4)

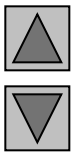
```c
/* Fig. 7.26: fig07_26.c
   Multipurpose sorting program using function pointers */
#include <stdio.h>
#define SIZE 10

/* 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()
{
   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" );

```

```
25    /* output original array */
26    for ( counter = 0; counter < SIZE; counter++ ) {
27       printf( "%5d", a[ counter ] );
28    } /* end for */
29
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
```



Outline

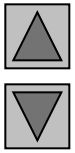
fig07_26.c (Part 2 of 4)



Outline

fig07_26.c (Part 3 of 4)

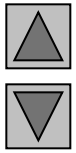
```
52 /* multipurpose bubble sort; parameter compare is a pointer to
53    the comparison function that determines sorting order */
54 void bubble( int work[], const int size, int (*compare)( int a, int b ) )
55 {
56    int pass;  /* pass counter */
57    int count; /* comparison counter */
58
59    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
```



Outline

fig07_26.c (Part 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 */
```



Outline

Program Output

```
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
```