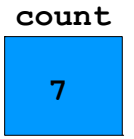
Pointers

Introduction

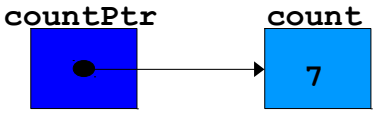
- Pointers
  - Powerful, but difficult to master
  - Simulate pass-by-reference
  - Close relationship with arrays and strings

Pointer Variable Declarations and Initialization

- Pointer variables
  - Contain memory addresses as values
  - Normally, variable contains specific value (direct reference)
  - Pointers contain address of variable that has specific value (indirect reference)



- Indirection
  - Referencing value through pointer



- Pointer declarations
  - ***** indicates variable is pointer

```
int *myPtr;
```

  - declares pointer to **int**, pointer of type **int ***
- Multiple pointers require multiple asterisks

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

Pointer Variable Declarations and Initialization

- Can declare pointers to any data type
- Pointer initialization
  - Initialized to **0**, **NULL**, or address

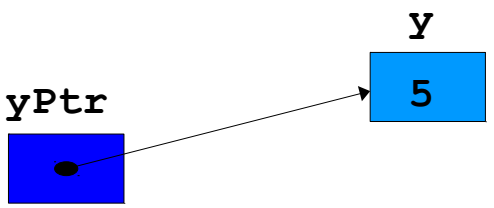
    0 or **NULL** points to nothing

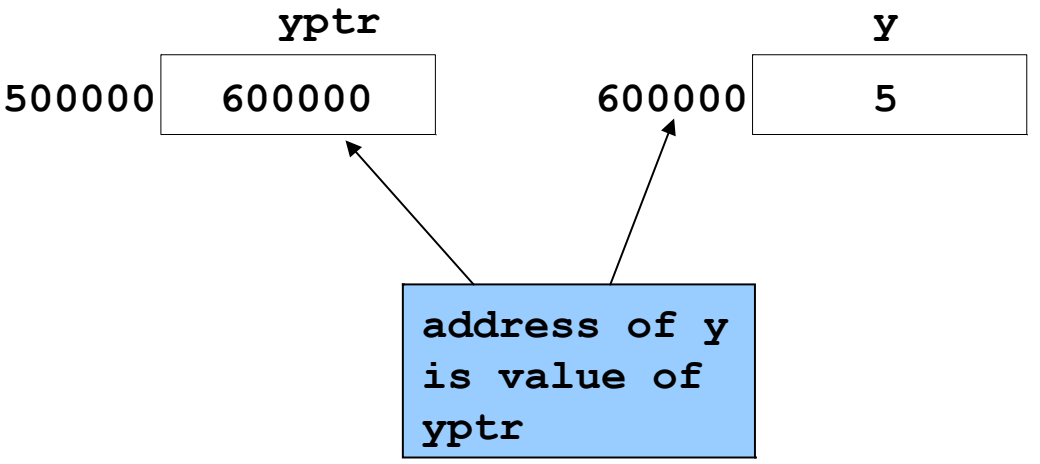
Pointer Operators

- **&** (address operator)
  - Returns memory address of its operand
  - Example

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

- **yPtr** "points to" **y**





Pointer Operators

- **`*`** (indirection/dereferencing operator)
  - Returns synonym for object its pointer operand points to
  - **`*yPtr`** returns **`y`** (because **`yPtr`** points to **`y`**).
  - dereferenced pointer is lvalue

```
*yptr = 9;       // assigns 9 to y
```

- **`*`** and **`&`** are inverses of each other

Pointer Operators

```
1       // Fig. 5.4: fig05_04.cpp
2       // Using the & and * operators.
3       #include <iostream>
4
5       using std::cout;
6       using std::endl;
7
8       int main()
9       {
10        int a;      // a is an integer
11        int *aPtr;  // aPtr is a pointer to an integer
12
13        a = 7;
14        aPtr = &a;  // aPtr assigned address of a
15
16        cout << "The address of a is " << &a
17             << "\nThe value of aPtr is " << aPtr;
18
19        cout << "\n\nThe value of a is " << a
20             << "\nThe value of *aPtr is " << *aPtr;
21
22        cout << "\n\nShowing that * and & are inverses of "
23             << "each other.\n&*aPtr = " << &*aPtr
24             << "\n*&aPtr = " << *&aPtr << endl;
25
26        return 0;  // indicates successful termination
27
28    } // end main
```

***** and **&** are inverses of each other

Pointer Operators

```
1       // Fig. 5.4: fig05_04.cpp
2       // Using the & and * operators.
3       #include <iostream>
4
5       using std::cout;
6       using std::endl;
7
8       int main()
9       {
10        int a;      // a is an integer
11        int *aPtr;  // aPtr is a pointer to an intege
12
13        a = 7;
14        aPtr = &a;  // aPtr assigned address of a
15
16        cout << "The address of a is " << &a
17             << "\nThe value of aPtr is " << aPtr;
18
19        cout << "\n\nThe value of a is " << a
20             << "\nThe value of *aPtr is " << *aPtr;
21
22        cout << "\n\nShowing that * and & are inverses of "
23             << "each other.\n&*aPtr = " << &*aPtr
24             << "\n*&aPtr = " << *&aPtr << endl;
25
26        return 0;  // indicates successful termination
27
28    } // end main
```

```
The address of a is 0012FED4
The value of aPtr is 0012FED4

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

Showing that * and & are inverses of each other.
&*aPtr = 0012FED4
*&aPtr = 0012FED4
```

***** and **&** are inverses of each other

Calling Functions by Reference

- 3 ways to pass arguments to function
  - Pass-by-value
  - Pass-by-reference with reference arguments
  - Pass-by-reference with pointer arguments
- `return` can return one value from function
- Arguments passed to function using reference arguments
  - Modify original values of arguments
  - More than one value “returned”

Calling Functions by Reference

- Pass-by-reference with pointer arguments
  - Simulate pass-by-reference
    - Use pointers and indirection operator
  - Pass address of argument using **&** operator
  - Arrays not passed with **&** because array name already pointer
  - ***** operator used as alias/nickname for variable inside of function

Calling Functions by value

```
1   // Fig. 5.6: fig05_06.cpp
2   // Cube a variable using pass-by-value.
3   #include <iostream>
4
5   using std::cout;
6   using std::endl;
7
8   int cubeByValue( int );   // prototype
9
10  int main()
11  {
12     int number = 5;
13
14     cout << "The original value of number is " << number;
15
16     // pass number by value to cubeByValue
17     number = cubeByValue( number );
18
19     cout << "\nThe new value of number is " << number << endl;
20
21     return 0;  // indicates successful termination
22
23  } // end main
24
25  // calculate and return cube of integer argument
26  int cubeByValue( int n )
27  {
28     return n * n * n; // cube local variable n and return result
29
30  } // end function cubeByValue
```

Calling Functions by value

```
1   // Fig. 5.6: fig05_06.cpp
2   // Cube a variable using pass-by-value.
3   #include <iostream>
4
5   using std::cout;
6   using std::endl;
7
8   int cubeByValue( int );   // prototype
9
10  int main()
11  {
12     int number = 5;
13
14     cout << "The original value of number is " <<
15
16     // pass number by value to cubeByValue
17     number = cubeByValue( number );
18
19     cout << "\nThe new value of number is " << number << endl;
20
21     return 0;  // indicates successful termination
22
23  } // end main
24
25  // calculate and return cube of integer argument
26  int cubeByValue( int n )
27  {
28     return n * n * n; // cube local varia
29
30  } // end function cubeByValue
```

```
The original value of number is 5

The new value of number is 125
```

Pass number by value; result **return**ed by **cubeByValue**

cubeByValue receives parameter passed-by-value

Cubes and **return**s local variable **n**

Calling Functions by reference

```
1       // Fig. 5.7: fig05_07.cpp
2       // Cube a variable using pass-by-reference
3       // with a pointer argument.
4       #include <iostream>
5
6       using std::cout;
7       using std::endl;
8
9       void cubeByReference( int * );   // prototype
10
11     int main()
12     {
13        int number = 5;
14
15        cout << "The original value of number is " << number;
16
17        // pass address of number to cubeByReference
18        cubeByReference( &number );
19
20        cout << "\nThe new value of number is " << number << endl;
21
22        return 0;  // indicates successful termination
23
24     } // end main
25
26     // calculate cube of *nPtr; modifies variable number in main
27     void cubeByReference( int *nPtr )
28     {
29        *nPtr = *nPtr * *nPtr * *nPtr;  // cube *nPtr
30
31     } // end function cubeByReference
```

Calling Functions by reference

```
1   // Fig. 5.7: fig05_07.cpp
2   // Cube a variable using pass-by-reference
3   // with a pointer argument.
4   #include <iostream>
5
6   using std::cout;
7   using std::endl;
8
9   void cubeByReference( int * );   // prototype
10
11  int main()
12  {
13     int number = 5;
14
15     cout << "The original value of number
16
17     // pass address of number to cubeByRe
18     cubeByReference( &number );
19
20     cout << "\nThe new value of number is " << number << endl;
21
22     return 0;  // indicates successful termination
23
24  } // end main
25
26  // calculate cube of *nPtr; modifies variable number in main
27  void cubeByReference( int *nPtr )
28  {
29     *nPtr = *nPtr * *nPtr * *nPtr;  // cube *nPtr
30
31  } // end function cubeByReference
```

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

Prototype indicates parameter is pointer to **int**

Apply address operator **&** to pass address of number to **cubeByReference**

cubeByReference modified variable **number**

cubeByReference receives address of **int** variable, i.e., pointer to an **int**

Modify and access **int** variable using indirection operator ***

Using `const` with Pointers

- **`const`** qualifier
  - Value of variable should not be modified
  - **`const`** used when function does not need to change a variable
- Principle of least privilege
  - Award function enough access to accomplish task, but no more
- Four ways to pass pointer to function
  - Nonconstant pointer to nonconstant data
    - Highest amount of access
  - Nonconstant pointer to constant data
  - Constant pointer to nonconstant data
  - Constant pointer to constant data
    - Least amount of access

Using const with pointers

```
1   // Fig. 5.10: fig05_10.cpp
2   // Converting lowercase letters to uppercase letters
3   // using a non-constant pointer to non-constant data.
4   #include <iostream>
5
6   using std::cout;
7   using std::endl;
8
9   #include <cctype>    // prototypes for islower and toupper
10
11  void convertToUppercase( char * );
12
13  int main()
14  {
15     char phrase[] = "characters and $32.98";
16
17     cout << "The phrase before conversion is: " << phrase;
18     convertToUppercase( phrase );
19     cout << "\nThe phrase after conversion is:  "
20          << phrase << endl;
21
22     return 0;  // indicates successful termination
23
24  } // end main
25
26  // convert string to uppercase letters
27  void convertToUppercase( char *sPtr )
28  {
29     while ( *sPtr != '\0' ) {   // current character is not '\0'
30
31        if ( islower( *sPtr ) )  // if character is lowercase,
32           *sPtr = toupper( *sPtr );  // convert to uppercase
33
34        ++sPtr;  // move sPtr to next character in string
35
36     } // end while
37
38  } // end function convertToUppercase
```

Using `const` with pointers

```
1   // Fig. 5.10: fig05_10.cpp
2   // Converting lowercase letters to uppercase letters
3   // using a non-constant pointer to non-constant data.
4   #include <iostream>
5
6   using std::cout;
7   using std::endl;
8
9   #include <cctype>    // prototypes for islower
10
11  void convertToUppercase( char * );
12
13  int main()
14  {
15     char phrase[] = "characters and $32.98";
16
17     cout << "The phrase before conversion is: " << phrase;
18     convertToUppercase( phrase );
19     cout << "\nThe phrase after conversion is:  "
20          << phrase << endl;
21
22     return 0;  // indicates successful termination
23
24  } // end main
25
26  // convert string to uppercase letters
27  void convertToUppercase( char *sPtr )
28  {
29     while ( *sPtr != '\0' ) {   // current character i
30
31        if ( islower( *sPtr ) )  // if character is low
32           *sPtr = toupper( *sPtr );  // convert
33
34        ++sPtr;  // move sPtr to next character i
35
36     } // end while
```

Parameter is nonconstant pointer to nonconstant data

convertToUppercase modifies variable phrase

Parameter **sPtr** nonconstant pointer to nonconstant data

Function **islower** returns **true** if character is lowercase

Function **toupper** returns corresponding uppercase character if original character lowercase; otherwise **toupper** returns original (uppercase) character

When operator **++** applied to pointer that points to array, memory address stored in pointer modified to point to next element of array.

Using const with pointers

```
1      // Fig. 5.10: fig05_10.cpp
2      // Converting lowercase letters to uppercase letters
3      // using a non-constant pointer to non-constant data.
4      #include <iostream>
5
6      using std::cout;
7      using std::endl;
8
9      #include <cctype>    // prototypes for islower and toupper
10
11     void convertToUppercase( char * );
12
13     int main()
14     {
15        char phrase[] = "characters and $32.98";
16
1
1
1
2
21
22        return 0;  // indicates successful termination
23
24     } // end main
25
26     // convert string to uppercase letters
27     void convertToUppercase( char *sPtr )
28     {
29        while ( *sPtr != '\0' ) {   // current character is not '\0'
30
31           if ( islower( *sPtr ) )  // if character is lowercase,
32              *sPtr = toupper( *sPtr );  // convert to uppercase
33
34           ++sPtr;  // move sPtr to next character in string
35
36        } // end while
37
38     } // end function convertToUppercase
```

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

Using const with pointers

```
1   // Fig. 5.11: fig05_11.cpp
2   // Printing a string one character at a time using
3   // a non-constant pointer to constant data.
4   #include <iostream>
5
6   using std::cout;
7   using std::endl;
8
9   void printCharacters( const char * );
10
11  int main()
12  {
13     char phrase[] = "print characters of a string";
14
15     cout << "The string is:\n";
16     printCharacters( phrase );
17     cout << endl;
18
19     return 0;  // indicates successful termination
20
21  } // end main
22
23  // sPtr cannot modify the character to which it points,
24  // i.e., sPtr is a "read-only" pointer
25  void printCharacters( const char *sPtr )
26  {
27     for ( ; *sPtr != '\0'; sPtr++ )   // no initialization
28        cout << *sPtr;
29
30  } // end function printCharacters
```

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

Using `const` with pointers

```
1   // Fig. 5.11: fig05_11.cpp
2   // Printing a string one character at a time using
3   // a non-constant pointer to constant data.
4   #include <iostream>
5
6   using std::cout;
7   using std::endl;
8
9   void printCharacters( const char * );
10
11  int main()
12  {
13     char phrase[] = "print characters of a string";
14
15     cout << "The string is:\n";
16     printCharacters( phrase );
17     cout << endl;
18
19     return 0;  // indicates successful termination
20
21  } // end main
22
23  // sPtr cannot modify the character to which it points,
24  // i.e., sPtr is a "read-only" pointer
25  void printCharacters( const char *sPtr )
26  {
27     for ( ; *sPtr != '\0'; sPtr++ )   // no initialization
28        cout << *sPtr;
29
30  } // end function printCharacters
```

Parameter is nonconstant pointer to constant data

Pass pointer **phrase** to function **printCharacters**

sPtr is nonconstant pointer to constant data; cannot modify character to which **sPtr** points

Increment **sPtr** to point to next character

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

Using const with pointers

```
1      // Fig. 5.12: fig05_12.cpp
2      // Attempting to modify data through a
3      // non-constant pointer to constant data.
4
5      void f( const int * );  // prototype
6
7      int main()
8      {
9         int y;
10
11       f( &y );   // f attempts illegal modification
12
13       return 0;  // indicates successful termination
14
15    } // end main
16
17    // xPtr cannot modify the value of the variable
18    // to which it points
19    void f( const int *xPtr )
20    {
21       *xPtr = 100;  // error: cannot modify a const object
22
23    } // end function f
```

```
d:\cpphtp4_examples\ch05\Fig05_12.cpp(21) : error C2166:
   l-value specifies const object
```

Using const with pointers

```
1   // Fig. 5.12: fig05_12.cpp
2   // Attempting to modify data through a
3   // non-constant pointer to constant data.
4
5   void f( const int * );  // prototype
6
7   int main()
8   {
9      int y;
10
11    f( &y );   // f attempts illegal modification
12
13    return 0;  // indicates successful t
14
15  } // end main
16
17  // xPtr cannot modify the value
18  // to which it points
19  void f( const int *xPtr )
20  {
21     *xPtr = 100;  // error: cannot modify a const object
22
23  } // end function f
```

Parameter is nonconstant pointer to constant data.

Pass address of **int** variable **y** to attempt illegal modification.

Attempt to modify **const** object pointed to by **xPtr**.

Error produced when attempting to compile

```
d:\cpphtp4_examples\ch05\Fig05_12.cpp(21) : error C2166:
   l-value specifies const object
```

Using `const` with Pointers

- **`const`** pointers
  - Always point to same memory location
  - Default for array name
  - Must be initialized when declared

Using const with pointers

```
1      // Fig. 5.13: fig05_13.cpp
2      // Attempting to modify a constant pointer to
3      // non-constant data.
4
5      int main()
6      {
7         int x, y;
8
9         // ptr is a constant pointer to an integer that can
10       // be modified through ptr, but ptr always points to the
11       // 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
```

```
d:\cpphtp4_examples\ch05\Fig05_13.cpp(15) : error C2166:
   l-value specifies const object
```

Using `const` with pointers

```
1   // Fig. 5.13: fig05_13.cpp
2   // Attempting to modify a constant pointer to
3   // non-constant data.
4
5   int main()
6   {
7      int x, y;
8
9      // ptr is a constant pointer to an integer that can
10     // be modified through ptr, but ptr always points to the
11     // same memory location.
12     int * const ptr = &x;
13
14     *ptr = 7;  // allowed: *ptr is not con
15     ptr = &y;  // error: ptr is const; can
16
17     return 0;  // indicates successful termination
18
19  } // end main
```

ptr is constant pointer to integer

Can modify **x** (pointed to by **ptr**) since x not constant

Cannot modify **ptr** to point to new address since **ptr** is constant

Line 15 generates compiler error by attempting to assign new address to constant pointer.

```
d:\cpphtp4_examples\ch05\Fig05_13.cpp(15) : error C2166:
   l-value specifies const object
```

Using `const` with pointers

```
1      // Fig. 5.14: fig05_14.cpp
2      // Attempting to modify a constant pointer to constant data.
3      #include <iostream>
4
5      using std::cout;
6      using std::endl;
7
8      int main()
9      {
10       int x = 5, y;
11
12       // ptr is a constant pointer to a constant integer.
13       // ptr always points to the same location; the integer
14       // at that location cannot be modified.
15       const int *const ptr = &x;
16
17       cout << *ptr << endl;
18
19       *ptr = 7;  // error: *ptr is const; cannot assign new value
20       ptr = &y;  // error: ptr is const; cannot assign new address
21
22       return 0;  // indicates successful termination
23
24   } // end main
```

```
d:\cpphtp4_examples\ch05\Fig05_14.cpp(19) : error C2166:
  l-value specifies const object
d:\cpphtp4_examples\ch05\Fig05_14.cpp(20) : error C2166:
  l-value specifies const object
```

Using `const` with pointers

```
1   // Fig. 5.14: fig05_14.cpp
2   // Attempting to modify a constant pointer to constant data.
3   #include <iostream>
4
5   using std::cout;
6   using std::endl;
7
8   int main()
9   {
10    int x = 5, y;
11
12    // ptr is a constant pointer to a constant integer.
13    // ptr always points to the same location; the integer
14    // at that location cannot be modified.
15    const int *const ptr = &x;
16
17    cout << *ptr << endl;
18
19    *ptr = 7;  // error: *ptr is
20    ptr = &y;  // error: ptr is c
21
22    return 0;  // indicates successful termination
23
24  } // end main
```

ptr is constant pointer to integer constant

Cannot modify **x** (pointed to by **ptr**) since ***ptr** declared constant.

Cannot modify **ptr** to point to new address since **ptr** is constant.

Line 19 generates compiler error by attempting to modify constant object.

Line 20 generates compiler error by attempting to assign new address to constant pointer.

```
d:\cpphtp4_examples\ch05\Fig05_14.cpp(19) : error C2166:
   l-value specifies const object
d:\cpphtp4_examples\ch05\Fig05_14.cpp(20) : error C2166:
   l-value specifies const object
```

Bubble Sort using Pass-by-Reference

- Implement **`bubbleSort`** using pointers
  - Want function **`swap`** to access array elements
    - Individual array elements: scalars
      - Passed by value by default
    - Pass by reference using address operator **`&`**

Bubble Sort using Pass-by-Reference

```
1     // Fig. 5.15: fig05_15.cpp
2     // This program puts values into an array, sorts the values into
3     // ascending order, and prints the resulting array.
4     #include <iostream>
5
6     using std::cout;
7     using std::endl;
8
9     #include <iomanip>
10
11    using std::setw;
12
13    void bubbleSort( int *, const int );    // prototype
14    void swap( int * const, int * const );  // prototype
15
16    int main()
17    {
18       const int arraySize = 10;
19       int a[ arraySize ] = { 2, 6, 4, 8, 10, 12, 89, 68, 45, 37 };
20
21       cout << "Data items in original order\n";
22
23       for ( int i = 0; i < arraySize; i++ )
24          cout << setw( 4 ) << a[ i ];
25
```

When used in an expression **`out << setw(n)`** or **`in >> setw(n)`**, sets the width parameter of the stream out or into exactly n.

Bubble Sort using Pass-by-Reference

```
26       bubbleSort( a, arraySize );  // sort the array
27
28       cout << "\nData items in ascending order\n";
29
30       for ( int j = 0; j < arraySize; j++ )
31          cout << setw( 4 ) << a[ j ];
32
33       cout << endl;
34
35       return 0;  // indicates successful termination
36
37    } // end main
38
39    // sort an array of integers using bubble sort algorithm
40    void bubbleSort( int *array, const int size )
41    {
42       // loop to control passes
43       for ( int pass = 0; pass < size - 1; pass++ )
44
45          // loop to control comparisons during each pass
46          for ( int k = 0; k < size - 1; k++ )
47
48             // swap adjacent elements if they are out of order
49             if ( array[ k ] > array[ k + 1 ] )
50                swap( &array[ k ], &array[ k + 1 ] );
```

Declare as **`int *array`** (rather than **`int array[]`**) to indicate function **`bubbleSort`** receives single-subscripted array.

Receives size of array as argument; declared **`const`** to ensure **`size`** not modified.

Bubble Sort using Pass-by-Reference

```
51
52    } // end function bubbleSort
53
54    // swap values at memory locations to which
55    // element1Ptr and element2Ptr point
56    void swap( int * const element1Ptr, int * const element2Ptr )
57    {
58       int hold = *element1Ptr;
59       *element1Ptr = *element2Ptr;
60       *element2Ptr = hold;
61
62    } // end function swap
```

Pass arguments by reference, allowing function to swap values at memory locations.

```
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
```

Bubble Sort Using Pass-by-Reference

- **`sizeof`**
  - Unary operator returns size of operand in bytes
  - For arrays, **`sizeof`** returns

    (size of 1 element) * (number of elements)
  - If **`sizeof( int ) = 4`**, then

```
int myArray[10];

cout << sizeof(myArray);
```

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

Bubble Sort Using Pass-by-Reference

```
1     // Fig. 5.16: fig05_16.cpp
2     // Sizeof operator when used on an array name
3     // returns the number of bytes in the array.
4     #include <iostream>
5
6     using std::cout;
7     using std::endl;
8
9     size_t getSize( double * );  // prototype
10
11    int main()
12    {
13       double array[ 20 ];
14
15       cout << "The number of bytes in the array is "
16            << sizeof( array );
17
18       cout << "\nThe number of bytes returned by getSize is "
19            << getSize( array ) << endl;
20
21       return 0;  // indicates successful termination
22
23    } // end main
24    //--------------------------------------------------------
25    // return size of ptr
26    size_t getSize( double *ptr )
27    {
28       return sizeof( ptr );
29
30    } // end function getSize
```

Bubble Sort Using Pass-by-Reference

```
1   // Fig. 5.16: fig05_16.cpp
2   // Sizeof operator when used on an array name
3   // returns the number of bytes in the array.
4   #include <iostream>
5
6   using std::cout;
7   using std::endl;
8
9   size_t getSize( double * );  // prototype
10
11  int main()
12  {
13     double array[ 20 ];
14
15     cout << "The number of bytes in the array is "
16          << sizeof( array );
17
18     cout << "\nThe number of bytes returned by getSize is "
19          << getSize( array ) << endl;
20
21     return 0;  // indicates successful termination
22
23  } // end main
24  //-------------------------------------
25  // return size of ptr
26  size_t getSize( double *ptr )
27  {
28     return sizeof( ptr );
29
30  } // end function getSize
```

```
The number of bytes in the array is 160
The number of bytes returned by getSize is 4
```

Operator **sizeof** applied to an array returns total number of bytes in array

Function **getSize** returns number of bytes used to store **array** address

Operator **sizeof** returns number of bytes of pointer.

Bubble Sort Using Pass-by-Reference

```
1       // Fig. 5.17: fig05_17.cpp
2       // Demonstrating the sizeof operator.
3       #include <iostream>
4
5       using std::cout;
6       using std::endl;
7
8       int main()
9       {
10        char c;
11        short s;
12        int i;
13        long l;
14        float f;
15        double d;
16        long double ld;
17        int array[ 20 ];
18        int *ptr = array;
19
```

Bubble Sort Using Pass-by-Reference

```
20       cout << "sizeof c = " << sizeof c
21            << "\tsizeof(char) = " << sizeof( char )
22            << "\nsizeof s = " << sizeof s
23            << "\tsizeof(short) = " << sizeof( short )
24            << "\nsizeof i = " << sizeof i
25            << "\tsizeof(int) = " << sizeof( int )
26            << "\nsizeof l = " << sizeof l
27            << "\tsizeof(long) = " << sizeof( long )
28            << "\nsizeof f = " << sizeof f
29            << "\tsizeof(float) = " << sizeof( float )
30            << "\nsizeof d = " << sizeof d
31            << "\tsizeof(double) = " << sizeof( double )
32            << "\nsizeof ld = " << sizeof ld
33            << "\tsizeof(long double) = " << sizeof( long double )
34            << "\nsizeof array = " << sizeof array
35            << "\nsizeof ptr = " << sizeof ptr
36            << endl;
37
38       return 0;  // indicates successful termination
39
40    } // end main
```

Operator **sizeof** can be used on variable name

Operator **sizeof** can be used on type name

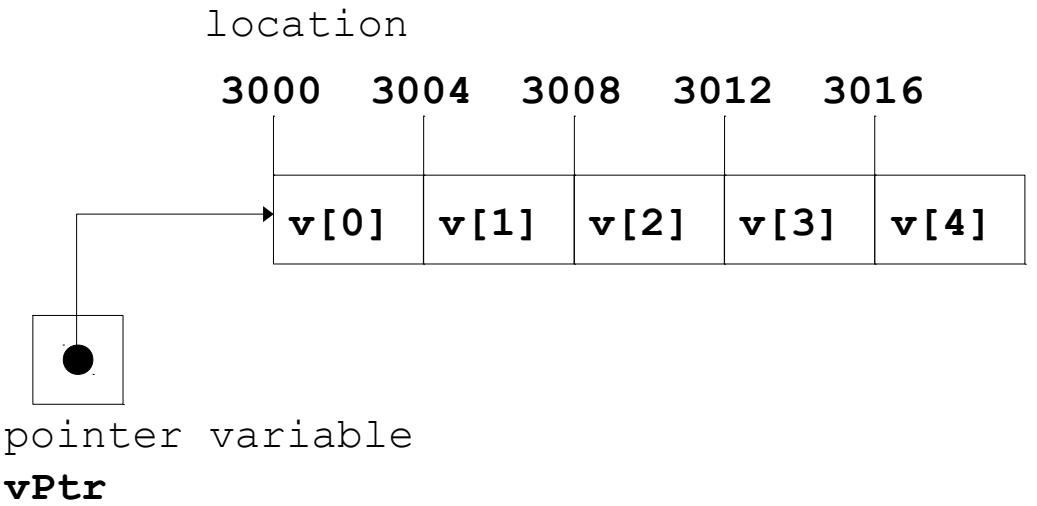
```
sizeof c = 1     sizeof(char) = 1
sizeof s = 2     sizeof(short) = 2
sizeof i = 4     sizeof(int) = 4
sizeof l = 4     sizeof(long) = 4
sizeof f = 4     sizeof(float) = 4
sizeof d = 8     sizeof(double) = 8
sizeof ld = 8    sizeof(long double) = 8
sizeof array = 80
sizeof ptr = 4
```

Pointer Expressions and Pointer Arithmetic

- Pointer arithmetic
  - Increment/decrement pointer (**++** or **--**)
  - Add/subtract an integer to/from a pointer(**+** or **+=** , **-** or **-=**)
  - Pointers may be subtracted from each other
  - Pointer arithmetic meaningless unless performed on pointer to array
- 5 element **int** array on a machine using 4 byte **int**s
  - **vPtr** points to first element **v[0]**, which is at location 3000

    vPtr = 3000
  - **vPtr += 2**; sets **vPtr** to **3008**

    vPtr points to **v[2]**



Pointer Expressions and Pointer Arithmetic

- Subtracting pointers
  - Returns number of elements between two addresses

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

- Pointer assignment
  - Pointer can be assigned to another pointer if both of same type
  - If not same type, cast operator must be used
  - Exception: pointer to **`void`** (type **`void *`**)
    - Generic pointer, represents any type
    - No casting needed to convert pointer to **`void`** pointer
    - **`void`** pointers cannot be dereferenced

Pointer Expressions and Pointer Arithmetic

- Pointer comparison
  - Use equality and relational operators
  - Comparisons meaningless unless pointers point to members of same array
  - Compare addresses stored in pointers
  - Example: could show that one pointer points to higher numbered element of array than other pointer
  - Common use to determine whether pointer is 0 (does not point to anything)

Relationship Between Pointers and Arrays

- Arrays and pointers closely related
  - Array name like constant pointer
  - Pointers can do array subscripting operations
- Accessing array elements with pointers
  - Element **`b[n]`** can be accessed by **`*( bPtr + n )`**
    - Called pointer/offset notation
  - Addresses
    - **`&b[3]`** same as **`bPtr + 3`**
  - Array name can be treated as pointer
    - **`b[3]`** same as **`*( b + 3 )`**
  - Pointers can be subscripted (pointer/subscript notation)
    - **`bPtr[3]`** same as **`b[3]`**

Pointers and arrays

```
1   // Fig. 5.20: fig05_20.cpp
2   // Using subscripting and pointer notations with arrays.
3
4   #include <iostream>
5
6   using std::cout;
7   using std::endl;
8
9   int main()
10  {
11     int b[] = { 10, 20, 30, 40 };
12     int *bPtr = b;   // set bPtr to point to array b
13
14     // output array b using array subscript notation
15     cout << "Array b printed with:\n"
16          << "Array subscript notation\n";
17
18     for ( int i = 0; i < 4; i++ )
19        cout << "b[" << i << "] = " << b[ i ] << '\n';
20
21     // output array b using the array name and
22     // pointer/offset notation
23     cout << "\nPointer/offset notation where "
24          << "the pointer is the array name\n";
25
```

Using array subscript notation

Pointers and arrays

```
26       for ( int offset1 = 0; offset1 < 4; offset1++ )
27          cout << "*(b + " << offset1 << ") = "
28               << *( b + offset1 ) << '\n';
29
30       // output array b using bPtr and array subscript n
31       cout << "\nPointer subscript notation\n";
32
33       for ( int j = 0; j < 4; j++ )
34          cout << "bPtr[" << j << "] = " << bPtr[ j ] << '\n';
35
36       cout << "\nPointer/offset notation\n";
37
38       // output array b using bPtr and pointer/offset notation
39       for ( int offset2 = 0; offset2 < 4; offset2++ )
40          cout << "*(bPtr + " << offset2 << ") = "
41               << *( bPtr + offset2 ) << '\n';
42
43       return 0;  // indicates successful termination
44
45    } // end main
```

Using array name and pointer/offset notation

Using pointer subscript notation

Using **bPtr** and pointer/offset notation

Pointers and arrays

```
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
```

Pointers and arrays - 2

```
1   // Fig. 5.21: fig05_21.cpp
2   // Copying a string using array notation
3   // and pointer notation.
4   #include <iostream>
5
6   using std::cout;
7   using std::endl;
8
9   void copy1( char *, const char * );  // prototype
10  void copy2( char *, const char * );  // prototype
11
12  int main()
13  {
14     char string1[ 10 ];
15     char *string2 = "Hello";
16     char string3[ 10 ];
17     char string4[] = "Good Bye";
18
19     copy1( string1, string2 );
20     cout << "string1 = " << string1 << endl;
21
22     copy2( string3, string4 );
23     cout << "string3 = " << string3 << endl;
24
25     return 0;  // indicates successful termination
```

Pointers and arrays - 2

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

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

Use array subscript notation to copy string in **s2** to character array **s1**

Use pointer notation to copy string in **s2** to character array in **s1**

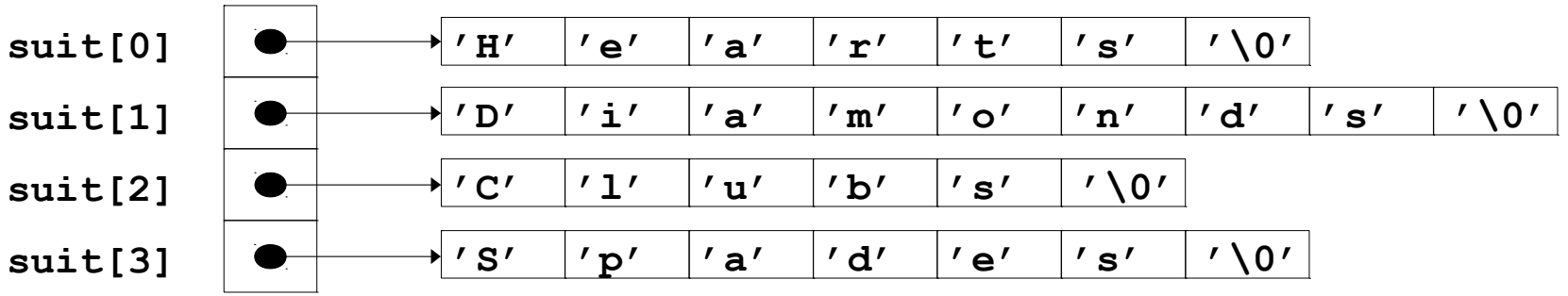
Increment both pointers to point to next elements in corresponding arrays

Arrays of Pointers

- Arrays can contain pointers
  - Commonly used to store array of strings

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

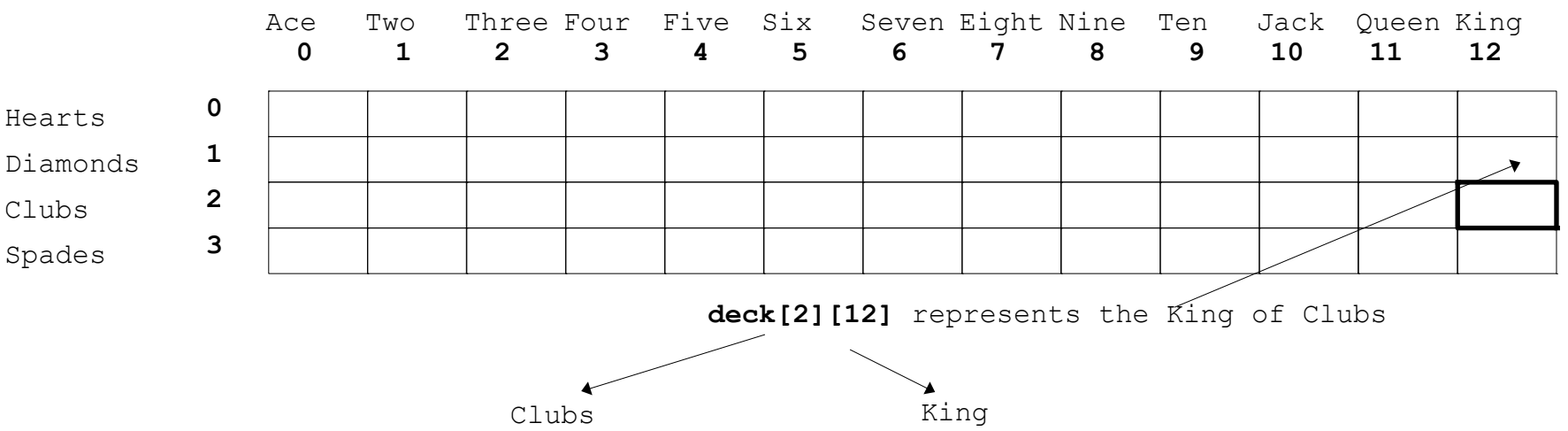
  - Each element of **`suit`** points to **`char *`** (a string)
  - Array does not store strings, only pointers to strings



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

Case Study: Card Shuffling and Dealing Simulation

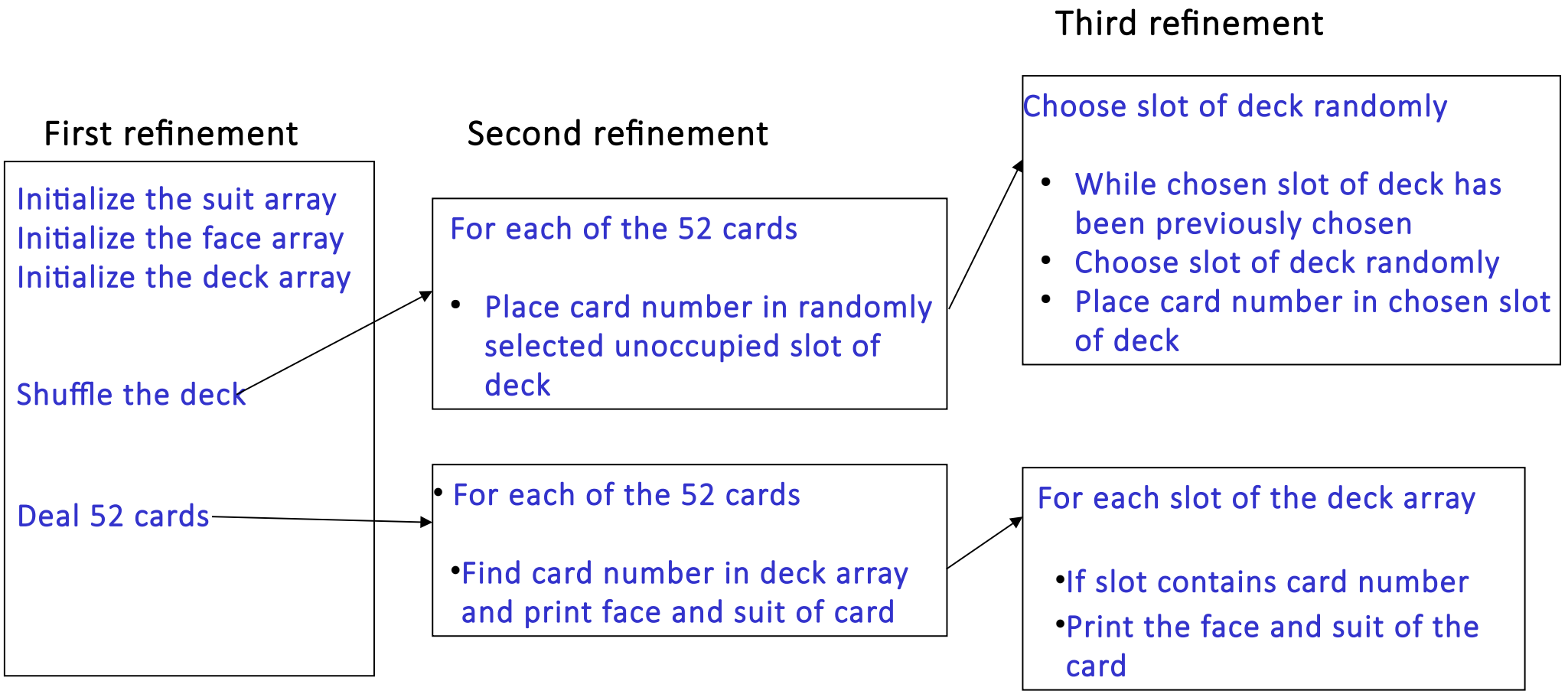
- Card shuffling program
  - Use an array of pointers to strings, to store suit names
  - Use a double scripted array (suit by value)



- Place 1-52 into the array to specify the order in which the cards are dealt

Case Study: Card Shuffling and Dealing Simulation

- Pseudocode for shuffling and dealing simulation



Card Shuffling

```
1     // Fig. 5.24: fig05_24.cpp
2     // Card shuffling dealing program.
3     #include <iostream>
4
5     using std::cout;
6     using std::left;
7     using std::right;
8
9     #include <iomanip>
10
11    using std::setw;
12
13    #include <cstdlib>  // prototypes for rand and srand
14    #include <ctime>    // prototype for time
15
16    // prototypes
17    void shuffle( int [][ 13 ] );
18    void deal( const int [][ 13 ], const char *[], const char *[] );
19
20    int main()
21    {
22       // initialize suit array
23       const char *suit[ 4 ] =
24          { "Hearts", "Diamonds", "Clubs", "Spades" };
25
```

suit array contains pointers to **char** arrays

Card Shuffling

```
26       // initialize face array
27       const char *face[ 13 ] =
28          { "Ace", "Deuce", "Three", "Four",
29            "Five", "Six", "Seven", "Eight",
30            "Nine", "Ten", "Jack", "Queen", "King" };
31
32       // initialize deck array
33       int deck[ 4 ][ 13 ] = { 0 };
34
35       srand( time( 0 ) );         // seed random number generator
36
37       shuffle( deck );
38       deal( deck, face, suit );
39
40       return 0;  // indicates successful termination
41
42    } // end main
43
```

face array contains pointers to **char** arrays

Card Shuffling

```
44    // shuffle cards in deck
45    void shuffle( int wDeck[][ 13 ] )
46    {
47       int row;
48       int column;
49
50       // for each of the 52 cards, choose slot of deck randomly
51       for ( int card = 1; card <= 52; card++ ) {
52
53          // choose new random location until unoccupied slo
54          do {
55             row = rand() % 4;
56             column = rand() % 13;
57          } while ( wDeck[ row ][ column ] != 0 ); // end do/while
58
59          // place card number in chosen slot of deck
60          wDeck[ row ][ column ] = card;
61
62       } // end for
63
64    } // end function shuffle
65
```

Current position is at randomly selected row and column

Card Shuffling

```
66    // deal cards in deck
67    void deal( const int wDeck[][ 13 ], const char *wFace[],
68               const char *wSuit[] )
69    {
70       // for each of the 52 cards
71       for ( int card = 1; card <= 52; card++ )
72
73          // loop through rows of wDeck
74          for ( int row = 0; row <= 3; row++ )
75
76             // loop through columns of wDeck for current row
77             for ( int column = 0; column <= 12; column++ )
78
79                // if slot contains current card, display card
80                if ( wDeck[ row ][ column ] == card ) {
81                   cout << setw( 5 ) << right << wFace[ column ]
82                        << " of " << setw( 8 ) << left
83                        << wSuit[ row ]
84                        << ( card % 2 == 0 ? '\n' : '\t' );
85
86                } // end if
87
88    } // end function deal
```

Cause face to be output right justified in field of 5 characters.

Cause suit to be output left justified in field of 8 characters

Card Shuffling

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

Function Pointers

- Pointers to functions
  - Contain 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
  - Returned from functions
  - Stored in arrays
  - Assigned to other function pointers

Function Pointers

- Calling functions using pointers
  - Assume parameter:

```
bool ( *compare ) ( int, int )
```

  - Execute function with either

```
( *compare ) ( int1, int2 )
```

    - Dereference pointer to function to execute
  - OR

```
compare( int1, int2 )
```

    - Could be confusing
    - User may think **`compare`** name of actual function in program

Function Pointers

```
1   // Fig. 5.25: fig05_25.cpp
2   // Multipurpose sorting program using function pointers.
3   #include <iostream>
4
5   using std::cout;
6   using std::cin;
7   using std::endl;
8
9   #include <iomanip>
10
11  using std::setw;
12
13  // prototypes
14  void bubble( int [], const int, bool (*)( int, int ) );
15  void swap( int * const, int * const );
16  bool ascending( int, int );
17  bool descending( int, int );
18
19  int main()
20  {
21     const int arraySize = 10;
22     int order;
23     int counter;
24     int a[ arraySize ] = { 2, 6, 4, 8, 10, 12, 89, 68, 45, 37 };
25
```

Parameter is pointer to function that receives two integer parameters and returns **`bool`** result

Function Pointers

```
26       cout << "Enter 1 to sort in ascending order,\n"
27            << "Enter 2 to sort in descending order: ";
28       cin >> order;
29       cout << "\nData items in original order\n";
30
31       // output original array
32       for ( counter = 0; counter < arraySize; counter++ )
33          cout << setw( 4 ) << a[ counter ];
34
35       // sort array in ascending order; pass function ascending
36       // as an argument to specify ascending sorting order
37       if ( order == 1 ) {
38          bubble( a, arraySize, ascending );
39          cout << "\nData items in ascending order\n";
40       }
41
42       // sort array in descending order; pass function descending
43       // as an agrument to specify descending sorting order
44       else {
45          bubble( a, arraySize, descending );
46          cout << "\nData items in descending order\n";
47       }
48
```

Function Pointers

```
49       // output sorted array
50       for ( counter = 0; counter < arraySize; counter++ )
51          cout << setw( 4 ) << a[ counter ];
52
53       cout << endl;
54
55       return 0;  // indicates successful termination
56
57    } // end main
58
59    // multipurpose bubble sort; parameter compare is
60    // the comparison function that determines sortin
61    void bubble( int work[], const int size,
62                 bool (*compare)( int, int ) )
63    {
64       // loop to control passes
65       for ( int pass = 1; pass < size; pass++ )
66
67          // loop to control number of comparisc
68          for ( int count = 0; count < size - 1;
69
70             // if adjacent elements are out of order, swap them
71             if ( (*compare)( work[ count ], work[ count + 1 ] ) )
72                swap( &work[ count ], &work[ count + 1 ] );
```

compare is pointer to function that receives two integer parameters and returns **bool** result

Parentheses necessary to indicate pointer to function

Call passed function **compare**; dereference pointer to execute function

Function Pointers

```
73
74    } // end function bubble
75
76    // swap values at memory locations to which
77    // element1Ptr and element2Ptr point
78    void swap( int * const element1Ptr, int * const element2Ptr )
79    {
80       int hold = *element1Ptr;
81       *element1Ptr = *element2Ptr;
82       *element2Ptr = hold;
83
84    } // end function swap
85
86    // determine whether elements are out of order
87    // for an ascending order sort
88    bool ascending( int a, int b )
89    {
90       return b < a;   // swap if b is less than a
91
92    } // end function ascending
93
```

Function Pointers

```
94    // determine whether elements are out of order
95    // for a descending order sort
96    bool descending( int a, int b )
97    {
98       return b > a;   // swap if b is greater than a
99
100  } // end function descending
```

```
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
```

Function Pointers

- Arrays of pointers to functions
  - Menu-driven systems
  - Pointers to each function stored in array of pointers to functions
    - All functions must have same return type and same parameter types
  - Menu choice → subscript into array of function pointers

Function Pointers

```
1   // Fig. 5.26: fig05_26.cpp
2   // Demonstrating an array of pointers to functions.
3   #include <iostream>
4
5   using std::cout;
6   using std::cin;
7   using std::endl;
8
9   // function prototypes
10  void function1( int );
11  void function2( int );
12  void function3( int );
13
14  int main()
15  {
16     // initialize array of 3 pointers to
17     // take an int argument and return void
18     void (*f[ 3 ])( int ) = { function1, function2, function3 };
19
20     int choice;
21
22     cout << "Enter a number between 0 and 2, 3 to end: ";
23     cin >> choice;
24
```

Array initialized with names of three functions; function names are pointers

Function Pointers

```
25       // process user's choice
26       while ( choice >= 0 && choice < 3 ) {
27
28          // invoke function at location choice in array f
29          // and pass choice as an argument
30          (*f[ choice ])( choice );
31
32          cout << "Enter a number between 0 and 2, 3 to end: ";
33          cin >> choice;
34       }
35
36       cout << "Program execution comple
37
38       return 0;  // indicates successful termination
39
40    } // end main
41
42    void function1( int a )
43    {
44       cout << "You entered " << a
45            << " so function1 was called\n\n";
46
47    } // end function1
48
```

Call chosen function by dereferencing corresponding element in array.

Function Pointers

```
49    void function2( int b )
50    {
51       cout << "You entered " << b
52            << " so function2 was called\n\n";
53
54    } // end function2
55
56    void function3( int c )
57    {
58       cout << "You entered " << c
59            << " so function3 was called\n\n";
60
61    } // 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.
```

POINTERS TO FUNCTIONS

The value of function pointers is that they allow us to define functions of functions. This is done by passing a function pointer as a parameter to another function.

EXAMPLE 6.15 The Sum of a Function

The sum of function has two parameters: the function pointer pf and the integer n:

The Sum of a Function

```
int sum(int (*) (int), int);
int square(int);
int cube(int);

main(){
      cout<<sum(square,4)<<endl;
      cout<<sum(cube,4)<<endl;
}

// Returns the sum f(0) + f(1) + f(2) + . . . + f(n-1):
int sum(int (*pf)(int k), int n)
{
      int s = 0;
      for (int i = 1; i <= n; i++)
          s += (*pf) (i);
      return s;
}
int square(int k){
return k*k;
}
int cube(int k){
return k*k*k;
}
```

Esercitazione 6

- Exercise 1 (pointerEs1.cpp)

  Write a program that:

- declares a variable double a and a double * aPtr
- assign to aPtr the address of a
- assign to a value of 5 using aPtr (i.e. it is forbidden to write a = 5)
- print a and aPtr
- Multiply by 2 using aPtr (i.e. it is forbidden to write a = a * 2.)
- print a and aPtr

- Exercise 2 (pointerEs2.cpp)

Write a program that:

- create an array of integers of size n
- assigns to the elements of this array the values 0, 1, 2, 3, ..., n using the pointer arithmetic
- print the array

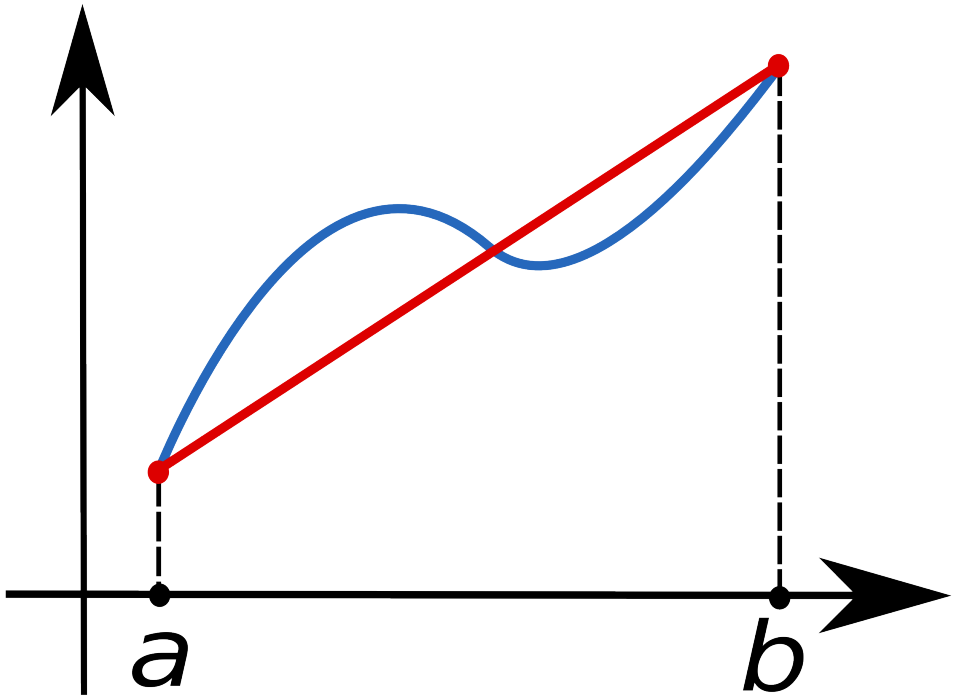
```
./pointerEs2
 a [0] = 0; aPtr = 0xbfffe110; * aPtr = 0
 a [1] = 1; aPtr = 0xbfffe118; * aPtr = 1
 a [2] = 2; aPtr = 0xbfffe120; * aPtr = 2
 a [3] = 3; aPtr = 0xbfffe128; * aPtr = 3
 a [4] = 4; aPtr = 0xbfffe130; * aPtr = 4
 a [5] = 5; aPtr = 0xbfffe138; * aPtr = 5
 a [6] = 6; aPtr = 0xbfffe140; * aPtr = 6
 a [7] = 7; aPtr = 0xbfffe148; * aPtr = 7
 a [8] = 8; aPtr = 0xbfffe150; * aPtr = 8
 a [9] = 9; aPtr = 0xbfffe158; * aPtr = 9
```

Interval : Numerical integration

Trapezoidal rule

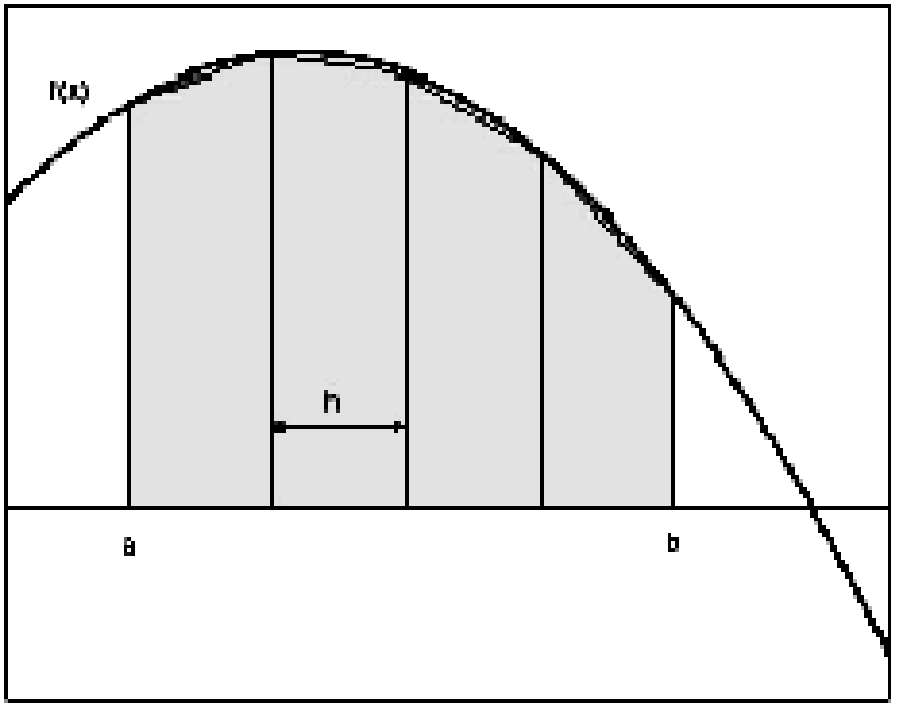
- The integral of a function is approximated with the area of a trapezium with vertexes: (a,f(a)), (b,f(b)), (b,0) e (a,0).
- This approximation is valid only if in the function in the considered interval is ~ flat.
- If this is not valid, the full range can be divided into N subintervals.

$$\int_a^b f(x)\,dx \approx (b-a)\frac{f(a)-f(b)}{2}$$



Trapezoidal rule

$$\int_a^b f(x)dx \approx \frac{b-a}{n}\left(\frac{f(a)+f(b)}{2}+\sum_{k=1}^{n-1} f\left(a+k\frac{b-a}{n}\right)\right)$$



Esercitazione 6

- **Exercise 3**

Calculate the integral of a function y = f (x) with the trapezoidal method:

area = DeltaX * ((y (0) + y (n)) / 2 + (y (1) + y (2) + ... + y (n-1)))

where n is the number of sub-intervals in which the integration domain and DeltaX is the amplitude of each sub-interval.

y (i-1) and y (i) are the values assumed by the function at the lower end and at the top of the i-th interval.

The user can specify the integration range and the number of sub-intervals during program execution.

The program must consist of:

*a main program,

*a function that calculates the values assumed by the integrand function at the ends of the sub-intervals and the integral with the trapezoidal rule.

– Suggestion: use an array to store the values of the function at the ends of each sub-intervals:
double func[n];

(main: useTrapezioidalIntegration.cpp

Function: TrapezioidalIntegration.{cpp,h})

Execution example:
./useTrapeziodalIntegration
Calculation of an integral with the Trapezium method
Low value of the integration interval: 1
High value of the integration interval: 2
Number of sub-intervals: 20
The integral of the function in the interval 1 2is :0.16772

Esercitazione 6

Exercise 4

Using the function that calculates the integral with the trapezoidal method developed for the previous exercise, write a program so that the user can specify the desired accuracy.

Tips:

- the user gives the epsilon parameter from the keyboard. The integral must be calculated in an iterative way, doubling the subintervals at each iteration, until (abs (area- oldArea) < epsilon * abs (area)).

area is the value of the integral in the current iteration, oldArea is the value in the previous iteration. abs is the absolute value (i.e. you have to include cmath).

- make sure that there are at least 3-4 iterations to avoid accidental convergences

- end the iterative process even in the absence of convergence after a maximum number of pre-set iterations

Execution example:

./useTrapezoidalIntegration2

Calculation of an integral with the Trapeziums method

Low value of the integration interval: 1

High value of the integration interval: 2

Precision: 0.01

The integral is: 0.167748

Esercitazione 6

Exercise 5 (Derivative.{cpp,h}, UseDerivative.cpp)

Write a function that returns the numerical derivative of a given function at a given point x, using a given tolerance h. Use the formula

$$f'(x) = (f(x+h)-f(x-h))/(2h)$$

This derivative() function has three arguments: a pointer to the function f, the x value, and the tolerance h.

In this exercise you have to implement and use the cube() function.

./derivative

Derivative example

x: 1

Tolerance: 0.001

The derivative of cube function in x=1 is 3

Characters and Strings

Fundamentals of Characters and Strings

- Character constant
  - Integer value represented as character in single quotes
  - `'z'` is integer value of `z`

    `122` in ASCII
- String
  - Series of characters treated as single unit
  - Can include letters, digits, special characters `+`, `-`, `*` ...
  - String literal (string constants)

    Enclosed in double quotes, for example:

    `"I like C++"`
  - Array of characters, ends with null character `'\0'`
  - String is constant pointer
    - Pointer to string's first character
    - Like arrays

Fundamentals of Characters and Strings

- String assignment
  - Character array
    - **`char color[] = "blue";`**
    - Creates 5 element **`char`** array **`color`**
      - last element is **`'\0'`**
  - Variable of type **`char *`**
    - **`char *colorPtr = "blue";`**
      - Creates pointer **`colorPtr`** to letter **`b`** in string **`"blue"`**
        - **`"blue"`** somewhere in memory
  - Alternative for character array
    - **`char color[] = { 'b', 'l', 'u', 'e', '\0' };`**

Fundamentals of Characters and Strings

- Reading strings
  - Assign input to character array **`word[ 20 ]`**

    `cin >> word`
  - Reads characters until whitespace or EOF
  - String could exceed array size

    `cin >> setw( 20 ) >> word;`
  - Reads 19 characters (space reserved for **`'\0'`**)

Fundamentals of Characters and Strings

- **`cin.getline`**
  - Read line of text
  - **`cin.getline( array, size, delimiter );`**
  - Copies input into specified **`array`** until either
    - One less than **`size`** is reached
    - **`delimiter`** character is input
  - Example

```
char sentence[ 80 ];
cin.getline( sentence, 80, '\n' );
```

String Manipulation Functions of the String-handling Library

- String handling library **`<cstring>`** provides functions to
  - Manipulate string data
  - Compare strings
  - Search strings for characters and other strings
  - Tokenize strings (separate strings into logical pieces)

String Manipulation Functions of the String-handling Library

`char *strcpy( char *s1, const char *s2 );`	Copies the string **s2** into the character array **s1**. The value of **s1** is returned.
`char *strncpy( char *s1, const char *s2, size_t n );`	Copies at most **n** characters of the string **s2** into the character array **s1**. The value of **s1** is returned.
`char *strcat( char *s1, const char *s2 );`	Appends the string **s2** to the string **s1**. The first character of **s2** overwrites the terminating null character of **s1**. The value of **s1** is returned.
`char *strncat( char *s1, const char *s2, size_t n );`	Appends at most **n** characters of string **s2** to string **s1**. The first character of **s2** overwrites the terminating null character of **s1**. The value of **s1** is returned.
`int strcmp( const char *s1, const char *s2 );`	Compares the string **s1** with the string **s2**. The function returns a value of zero, less than zero or greater than zero if **s1** is equal to, less than or greater than **s2**, respectively.

String Manipulation Functions of the String-handling Library

`int strncmp( const char *s1, const char *s2, size_t n );`	Compares up to **n** characters of the string **s1** with the string **s2**. The function returns zero, less than zero or greater than zero if **s1** is equal to, less than or greater than **s2**, respectively.
`char *strtok( char *s1, const char *s2 );`	A sequence of calls to **strtok** breaks string **s1** into "tokens"—logical pieces such as words in a line of text—delimited by characters contained in string **s2**. The first call contains **s1** as the first argument, and subsequent calls to continue tokenizing the same string contain **NULL** as the first argument. A pointer to the current token is returned by each call. If there are no more tokens when the function is called, **NULL** is returned.
`size_t strlen( const char *s );`	Determines the length of string **s**. The number of characters preceding the terminating null character is returned.

String Manipulation Functions of the String-handling Library

- Copying strings
  - **`char *strcpy( char *s1, const char *s2 )`**
    - Copies second argument into first argument
      - First argument must be large enough to store string and terminating null character
  - **`char *strncpy( char *s1, const char *s2, size_t n )`**
    - Specifies number of characters to be copied from string into array
    - Does not necessarily copy terminating null character

String Manipulation Functions of the String-handling Library

```
1      // Fig. 5.28: fig05_28.cpp
2      // Using strcpy and strncpy.
3      #include <iostream>
4
5      using std::cout;
6      using std::endl;
7
8      #include <cstring>   // prototypes for strcpy and strncpy
9
10     int main()
11     {
12        char x[] = "Happy Birthday to You";
13        char y[ 25 ];
14        char z[ 15 ];
15
16        strcpy( y, x );  // copy contents of x into y
17
18        cout << "The string in array x is: " << x
19             << "\nThe string in array y is: " << y
20
21        // copy first 14 characters of x into z
22        strncpy( z, x, 14 );  // does not copy null characte
23        z[ 14 ] = '\0';       // append '\0' to z's contents
24
25        cout << "The string in array z is: " << z << endl;
26
27        return 0;  // indicates successful termination
28
29     } // end main
```

```
The string in array x is: Happy Birthday to You
The string in array y is: Happy Birthday to You
The string in array z is: Happy Birthday
```

<cstring> contains prototypes for **strcpy** and **strncpy**

Copy entire string in array **x** into array **y**

Copy first 14 characters of array **x** into array **z**. Note that this does not write terminating null character

Append terminating null character

String to copy.

Copied string using **strcpy**.

Copied first 14 characters using **strncpy**

String Manipulation Functions of the String-handling Library

- Concatenating strings
  - **`char *strcat( char *s1, const char *s2 )`**
    - Appends second argument to first argument
    - First character of second argument replaces null character terminating first argument
    - Ensure first argument large enough to store concatenated result and null character
  - **`char *strncat( char *s1, const char *s2, size_t n )`**
    - Appends specified number of characters from second argument to first argument
    - Appends terminating null character to result

String Manipulation Functions of the String-handling Library

```
1   // Fig. 5.29: fig05_29.cpp
2   // Using strcat and strncat.
3   #include <iostream>
4
5   using std::cout;
6   using std::endl;
7
8   #include <cstring>   // prototypes for strcat and strncat
9
10  int main()
11  {
12     char s1[ 20 ] = "Happy ";
13     char s2[] = "New Year ";
14     char s3[ 40 ] = "";
15
16     cout << "s1 = " << s1 << "\ns2 = " << s2;
17
18     strcat( s1, s2 );  // concatenate s2 to s1
19
20     cout << "\n\nAfter strcat(s1,
21          << "\ns2 = " << s2;
22
23     // concatenate first 6 characters of s1 to s3
24     strncat( s3, s1, 6 );  // places '\0' after last character
25
```

<cstring> contains prototypes for **strcat** and **strncat**

Append **s2** to **s1**

Append first 6 characters of **s1** to **s3**

String Manipulation Functions of the String-handling Library

```
26       cout << "\n\nAfter strncat" << " " << s1
27            << "\ns3 = " << s3;
28
29       strcat( s3, s1 );  // concatenate s1 to s3
30       cout << "\n\nAfter strcat(s3, s1):\ns1 = " << s1
31            << "\ns3 = " << s3 << endl;
32
33       return 0;  // indicates successful termination
34
35    } // end main
```

Append **s1** to **s3**

```
s1 = Happy
s2 = New Year

After strcat(s1, s2):
s1 = Happy New Year
s2 = New Year

After strncat(s3, s1, 6):
s1 = Happy New Year
s3 = Happy

After strcat(s3, s1):
s1 = Happy New Year
s3 = Happy Happy New Year
```

String Manipulation Functions of the String-handling Library

- Comparing strings
  - Characters represented as numeric codes
    - Strings compared using numeric codes
  - Character codes / character sets
    - ASCII
      - “American Standard Code for Information Interchage”
    - EBCDIC
      - “Extended Binary Coded Decimal Interchange Code”

String Manipulation Functions of the String-handling Library

- Comparing strings
  - **`int strcmp( const char *s1, const char *s2 )`**
    - Compares character by character
    - Returns
      - Zero if strings equal
      - Negative value if first string less than second string
      - Positive value if first string greater than second string
  - **`int strncmp( const char *s1,`**
    `const char *s2, size_t n )`
    - Compares up to specified number of characters
    - Stops comparing if reaches null character in one of arguments

String Manipulation Functions of the String-handling Library

```
1   // Fig. 5.30: fig05_30.cpp
2   // Using strcmp and strncmp.
3   #include <iostream>
4
5   using std::cout;
6   using std::endl;
7
8   #include <iomanip>
9
10  using std::setw;
11
12  #include <cstring>  // prototypes for strcmp and strncmp
13
14  int main()
15  {
16     char *s1 = "Happy New Year";
17     char *s2 = "Happy New Year";
18     char *s3 = "Happy Holidays";
19
20     cout << "s1 = " << s1 << "\ns2 = " << s
21          << "\ns3 = " << s3 << "\n\nstrcmp(
22          << setw( 2 ) << strcmp( s1, s2 )
23          << "\nstrcmp(s1, s3) = " << setw( 2 )
24          << strcmp( s1, s3 ) << "\nstrcmp(s3, s1) = "
25          << setw( 2 ) << strcmp( s3, s1 );
```

<cstring> contains prototypes for **strcmp** and **strncmp**.

Compare **s1** and **s2**.

Compare **s1** and **s3**.

Compare **s3** and **s1**.

String Manipulation Functions of the String-handling Library

```
26
27       cout << "\n\nstrncmp(s1, s3, 6) = " << setw( 2 )
28            << strncmp( s1, s3, 6 ) << "\nstrncmp(s1, s3, 7) = "
29            << setw( 2 ) << strncmp( s1, s3, 7 )
30            << "\nstrncmp(s3, s1, 7) = "
31            << setw( 2 ) << strncmp( s3, s1, 7 ) << endl;
32
33       return 0;  // indicates successful termination
34
35    } // end main
```

Compare up to 6 characters of **s1** and **s3**

Compare up to 7 characters of **s1** and **s3**

Compare up to 7 characters of **s3** and **s1**

```
s1 = Happy New Year
s2 = Happy New Year
s3 = Happy Holidays

strcmp(s1, s2) =  0
strcmp(s1, s3) =  1
strcmp(s3, s1) = -1

strncmp(s1, s3, 6) =  0
strncmp(s1, s3, 7) =  1
strncmp(s3, s1, 7) = -1
```

String Manipulation Functions of the String-handling Library

- Tokenizing
  - Breaking strings into tokens, separated by delimiting characters
  - Tokens usually logical units, such as words (separated by spaces)
  - **`"This is my string"`** has 4 word tokens (separated by spaces)
  - **`char *strtok( char *s1, const char *s2 )`**
    - Multiple calls required
      - First call contains two arguments, string to be tokenized and string containing delimiting characters
        - Finds next delimiting character and replaces with null character
    - Subsequent calls continue tokenizing
      - Call with first argument **`NULL`**

String Manipulation Functions of the String-handling Library

```
1   // Fig. 5.31: fig05_31.cpp
2   // Using strtok.
3   #include <iostream>
4
5   using std::cout;
6   using std::endl;
7
8   #include <cstring>  // prototype for strtok
9
10  int main()
11  {
12     char sentence[] = "This is a sentence with 7 tokens";
13     char *tokenPtr;
14
15     cout << "The string to be tokenized
16          << "\n\nThe tokens are:\n\n";
17
18     // begin tokenization of sentence
19     tokenPtr = strtok( sentence, " " );
20
21     // continue tokenizing sentence until tokenPtr becomes NULL
22     while ( tokenPtr != NULL ) {
23        cout << tokenPtr << '\n';
24        tokenPtr = strtok( NULL, " " );  // get next token
25
26     } // end while
27
28     cout << "\nAfter strtok, sentence =
29
30     return 0;  // indicates successful
31
32  } // end main
```

<cstring> contains prototype for **strtok**

First call to **strtok** begins tokenization

Subsequent calls to **strtok** with **NULL** as first argument to indicate continuation

String Manipulation Functions of the String-handling Library

```
The string to be tokenized is:
This is a sentence with 7 tokens

The tokens are:

This
is
a
sentence
with
7
tokens

After strtok, sentence = This
```

String Manipulation Functions of the String-handling Library

- Determining string lengths
  - **`size_t strlen( const char *s )`**
    - Returns number of characters in string
      - Terminating null character not included in length

String Manipulation Functions of the String-handling Library

```
1     // Fig. 5.32: fig05_32.cpp
2     // Using strlen.
3     #include <iostream>
4
5     using std::cout;
6     using std::endl;
7
8     #include <cstring>  // prototype for strlen
9
10    int main()
11    {
12       char *string1 = "abcdefghijklmnopqrstuvwxyz";
13       char *string2 = "four";
14       char *string3 = "Boston";
15
16       cout << "The length of \"" << string1
17            << "\" is " << strlen( string1 )
18            << "\nThe length of \"" << string2
19            << "\" is " << strlen( string2 )
20            << "\nThe length of \"" << string3
21            << "\" is " << strlen( string3 ) << endl;
22
23       return 0;  // indicates successful termination
24
25    } // end main
```

<cstring> contains prototype for **strlen**.

Using **strlen** to determine length of strings

```
The length of "abcdefghijklmnopqrstuvwxyz" is 26
The length of "four" is 4
The length of "Boston" is 6
```