Classes Part II

Quick Recap on Classes

- A class is like an array: it is a derived type whose elements have other types.
- Unlike an array, the elements of a class may have different types.
- Furthermore, some elements of a class may be functions, including *operators*.
- Although any region of storage may generally be regarded as an "object", the word is usually used to describe variables whose type is a class.
- "Object-oriented programming" involves programs that use classes.

Class Declaration

Here is a declaration for a class whose objects represent rational numbers (i.e., fractions):

```
class Ratio
{ public:
   void assign(int, int);
   double convert();
   void invert();
   void print();
   private:
   int num, den;
};
```

Class Declaration

Here is a declaration for a class whose objects represent rational numbers (i.e., fractions):

```
class Ratio
{ public:
   void assign(int, int);
   double convert();
   void invert();
   void print();
   private:
   int num, den;
};
```

class name

Key word class

Function are called member function (methods)

Function are called data member

Required ;

Public members are accessible from outside the class

Private are accessible only from within the class

Class Declaration

```
class Ratio
{ public:
     void assign(int, int);
     double convert();
     void invert();
     void print();
  private:
     int num, den;
};
int main()
{ Ratio x;
     x.assign(22,7);
     cout << "x = ";
     x.print();
     cout << " = " << x.convert() << endl;
     x.invert();
     cout << "1/x = "; x.print();
     cout << endl;
}
```

```
void Ratio::assign(int numerator, int denominator)
{
num = numerator;
den = denominator;
}
double Ratio::convert()
{
return double(num)/den;
}
void Ratio::invert()
{
int temp = num;
Num = den;
den = temp;
}
void Ratio::print()
{
cout << num << '/' << den;
}
```

```
x = 22/7 = 3.14286
1/x = 7/22
```

Constructor

- The Ratio class defined in previews slide uses the assign() function to initialize its objects.
- It would be more natural to have this initialization occur when the objects are declared.
- That's how ordinary (predefined) types work:

```
int n = 22;
char* s = "Hello";
```

- C++ allows this simpler style of initialization to be done for class objects using *constructor* functions.
- A constructor is a **member function** that is invoked automatically when an object is declared.
- A constructor function must have the same name as the class itself, and it is declared without return type.

Constructor

```
class Ratio
{ public:
     Ratio(int n, int d) { num = n; den = d; }
     void print() { cout << num << '/' << den; }
  private:
     int num, den;
};

int main()
{
     Ratio x(-1,3), y(22,7);
     cout << "x = ";
     x.print();
     cout << " and y = ";
     y.print();
}
```

```
x = -1/3 and y = 22/7
```

A class's constructor "constructs" the class objects by allocating and initializing storage for the objects and by performing any other tasks that are programmed into the function.
It literally creates a live object from a pile of unused bits.

More constructor

```
class Ratio
{ public:
    Ratio() { num = 0; den = 1; }
    Ratio(int n) { num = n; den = 1; }
    Ratio(int n, int d) { num = n; den = d; }
    void print() { cout << num << '/' << den; }
  private:
    int num, den;
};

int main()
{
    Ratio x, y(4), z(22,7);
    cout << "x = ";
    x.print();
    cout << "\ny = ";
    y.print();
    cout << "\nz = ";
    z.print();
}
```

This version of the Ratio class has three constructors:

- The first has no parameters and initializes the declared object with the default values 0 and 1.
- The second constructor has one integer parameter and initializes the object to be the fractional equivalent to that integer.
- The third constructor is the same as in previous slide

Constructor initialization lists

- Most constructors do nothing more than initialize the object's member data.
- C++ provides a special syntactical device for constructors that simplifies this code. The device is an initialization list.
- The third constructor of the previous slide can be rewritten using an initialization list:

```
Ratio(int n, int d) : num(n), den(d) { }
```

- The assignment statements in the function's body that assigned n to num and d to den are removed. Their action is handled by the initialization list shown in boldface.
- Note that the list begins with a colon and precedes the function body which is now empty.

Constructor initialization lists

```
class Ratio
{ public:
    Ratio() : num(0), den(1) { }
    Ratio(int n) : num(n), den(1) { }
    Ratio(int n, int d) : num(n), den(d) { }
private:
    int num, den;
};
```

Of course, these three separate constructors are not necessary.
They can be combined into a single constructor:

```
class Ratio
{ public:
    Ratio(int n=0, int d=1) : num(n), den(d) { }
private:
    int num, den;
};
int main()
{
    Ratio x, y(4), z(22,7);
}
```

Access function

Although a class's member data are usually declared to be private to limit access to them, it is also common to include public member functions that provide read-only access to the data.

Such functions are called access functions. (Usually preceded by "Get" and "Set")

```
class Ratio
{ public:
    Ratio(int n=0, int d=1) : num(n), den(d) { }
    int GetNumerator() const { return num; }
    int GetDenominator() const { return den; }
  private:
    int num, den;
};

int main()
{
    Ratio x(22,7);
    cout << x.GetNumerator() << '/' << x.GetDenominator() << endl;
}
```

The copy constructor

- Every class has at least two constructors. These are identified by their unique declarations:

```
X(); // default constructor
X(const X&); // copy constructor
```

- where `X` is the class identifier. For example, these two special constructors for a Widget class would be declared:

```
Widget(); // default constructor
Widget(const Widget&); // copy constructor
```

- The first of these two special constructors is called the *default constructor*; it is called automatically whenever an object is declared in the simplest form, like this:

```
Widget x;
```

- The second of these two special constructors is called the *copy constructor*; it is called automatically whenever an object is copied (i.e., duplicated), like this:

```
Widget y(x);
```

- If either of these two constructors is not defined explicitly, then it is automatically defined implicitly by the system.
- The copy constructor takes one parameter: the object that it is going to copy. That object is passed by constant reference because it should not be changed.
- When the copy constructor is called, it copies the complete state of an existing object into a new object of the same class. If the class definition does not explicitly include a copy constructor (as all the previous examples have not), then the system automatically creates one by default.

Example

```
class Ratio
{ public:
    Ratio(int n=0, int d=1) : num(n), den(d) { reduce(); }
    Ratio(const Ratio& r) : num(r.num), den(r.den) { }
    void print() { cout << num << '/' << den; }
  private:
    int num, den;
    void reduce();
};

int main()
{
    Ratio x(100,360);
    Ratio y(x);
    cout << "x = ";
    x.print();
    cout << ", y = ";
    y.print();
}
```

```
x = 5/18, y = 5/18
```

The class destructor

- When an object is created, a constructor is called automatically to manage its birth. Similarly, when an object comes to the end of its life, another special member function is called automatomatically to manage its death.
- This function is called a *destructor* .
- Each class has exactly one destructor. If it is not defined explicitly in the class definition, then like the default constructor, the copy constructor, and the assignment operator, the destructor is created automatically.

The class destructor

```
class Ratio
{ public:
     Ratio() { cout << "OBJECT IS BORN.\n"; }
     ~Ratio() { cout << "OBJECT DIES.\n"; }
  private:
     int num, den;
};

int main()
{
 { Ratio x; // beginning of scope for x
   cout << "Now x is alive.\n";
 }// end of scope for x

cout << "Now between blocks.\n";

{ Ratio y;
 cout << "Now y is alive.\n";
}
}
```

```
OBJECT IS BORN.
Now x is alive.
OBJECT DIES.
Now between blocks.
OBJECT IS BORN.
Now y is alive.
OBJECT DIES.
```

`const` (Constant) Objects and member function

It is good programming practice to make an object constant if it should not be changed. This is done with the `const` keyword:

```
const char BLANK = ' ';
const int MAX_INT = 2147483647;
const double PI = 3.141592653589793;
void init(float a[], const int SIZE);
```

Like variables and function parameters, objects may also be declared to be constant:

```
const Ratio PI(22,7);
```

However, when this is done, the C++ compiler restricts access to the object's member functions.

For example, with the `Ratio` class defined previously, the `print()` function could not be called for this object:

```
PI.print(); //error: call not allowed
```

In fact, unless we modify our class definition, the only member functions that could be called for `const` objects would be the constructors and the destructor.

To overcome this restriction, we must declare as constant those member functions that we want to be able to use with `const` objects.

A function is declared constant by inserting the `const` keyword between its parameter list and its body:

```
void print() const { cout << num << '/' << den << endl; }
```

This modification of the function definition will allow it to be called for constant objects:

```
const Ratio PI(22,7);
PI.print(); // o.k. now
```

```
1   // Fig. 7.1: time5.h
2   // Definition of class Time.
3   // Member functions defined in time5.cpp.
4   #ifndef TIME5_H
5   #define TIME5_H
6
7   class Time {
8
9   public:
10    Time( int = 0, int = 0, int = 0 );  // default constructor
11
12    // set functions
13    void setTime( int, int, int );  // set time
14    void setHour( int );            // set hour
15    void setMinute( int );          // set min
16    void setSecond( int );          // set sec
17
18    // get functions (normally declared const)
19    int getHour() const;            // return hour
20    int getMinute() const;          // return mi
21    int getSecond() const;          // return se
22
23    // print functions (normally declared const)
24    void printUniversal() const;    // print universal time
25    void printStandard();           // print standard time
26
27  private:
28    int hour;     // 0 - 23 (24-hour clock format)
29    int minute;   // 0 - 59
30    int second;   // 0 - 59
31
32  }; // end class Time
33
34  #endif
```

Declare **const** get functions

Declare **const** function **printUniversal**

`const` (Constant) Objects and `const` Member Functions

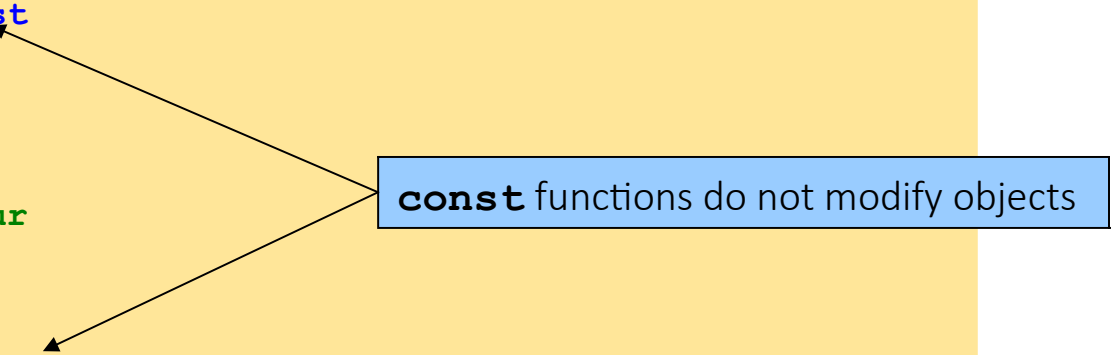
```
1     // Fig. 7.2: time5.cpp
2     // Member-function definitions for class Time.
3     #include <iostream>
4
5     using std::cout;
6
7     #include <iomanip>
8
9     using std::setfill;
10    using std::setw;
11
12    // include definition of class Time from time5.h
13    #include "time5.h"
14
15    // constructor function to initialize private data;
16    // calls member function setTime to set variables;
17    // default values are 0 (see class definition)
18    Time::Time( int hour, int minute, int second )
19    {
20       setTime( hour, minute, second );
21
22    } // end Time constructor
23
```

`const` (Constant) Objects and `const` Member Functions

```
24    // set hour, minute and second values
25    void Time::setTime( int hour, int minute, int second )
26    {
27       setHour( hour );
28       setMinute( minute );
29       setSecond( second );
30
31    } // end function setTime
32
33    // set hour value
34    void Time::setHour( int h )
35    {
36       hour = ( h >= 0 && h < 24 ) ? h : 0;
37
38    } // end function setHour
39
40    // set minute value
41    void Time::setMinute( int m )
42    {
43       minute = ( m >= 0 && m < 60 ) ? m : 0;
44
45    } // end function setMinute
46
```

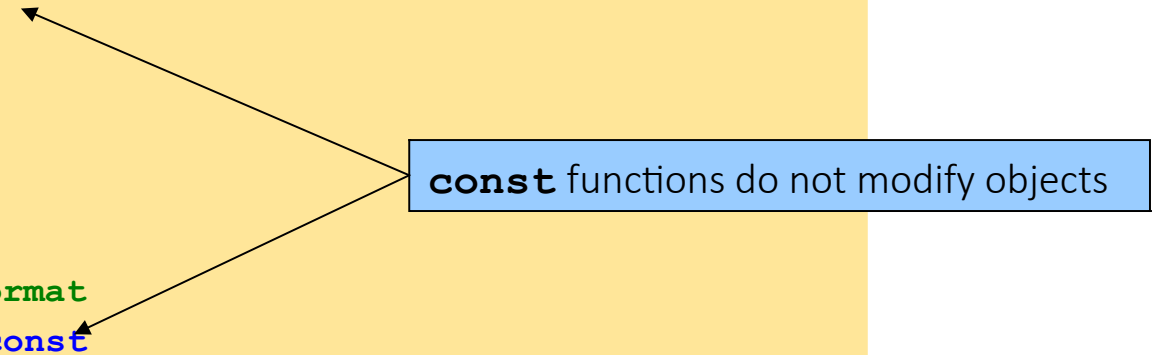
`const` (Constant) Objects and `const` Member Functions

```
47    // set second value
48    void Time::setSecond( int s )
49    {
50       second = ( s >= 0 && s < 60 ) ? s : 0;
51
52    } // end function setSecond
53
54    // return hour value
55    int Time::getHour() const
56    {
57       return hour;
58
59    } // end function getHour
60
61    // return minute value
62    int Time::getMinute() const
63    {
64       return minute;
65
66    } // end function getMinute
67
```



`const` (Constant) Objects and `const` Member Functions

```
68    // return second value
69    int Time::getSecond() const
70    {
71       return second;
72
73    } // end function getSecond
74
75    // print Time in universal format
76    void Time::printUniversal() const
77    {
78       cout << setfill( '0' ) << setw( 2 ) << hour << ":"
79            << setw( 2 ) << minute << ":"
80            << setw( 2 ) << second;
81
82    } // end function printUniversal
83
84    // print Time in standard format
85    void Time::printStandard() // note lack of const declaration
86    {
87       cout << ( ( hour == 0 || hour == 12 ) ? 12 : hour % 12 )
88            << ":" << setfill( '0' ) << setw( 2 ) << minute
89            << ":" << setw( 2 ) << second
90            << ( hour < 12 ? " AM" : " PM" );
91
92    } // end function printStandard
```



`const` (Constant) Objects and `const` Member Functions

```
1       // Fig. 7.3: fig07_03.cpp
2       // Attempting to access a const object with
3       // non-const member functions.
4
5       // include Time class definition from time5.h
6       #include "time5.h"
7
8       int main()
9       {
10        Time wakeUp( 6, 45, 0 );        // non-constant object
11        const Time noon( 12, 0, 0 );    // constant object
12
```

Declare **noon** as a **const** object

Note that non-const constructor can initialize **const** object

`const` (Constant) Objects and `const` Member Functions

```
13                                  // OBJECT      MEMBER FUNCTION
14        wakeUp.setHour( 18 );     // non-const   non-const
15
16        noon.setHour( 12 );       // const       non-const
17
18        wakeUp.getHour();         // non-const   const
19
20        noon.getMinute();         // const       c
21        noon.printUniversal();    // const       const
22
23        noon.printStandard();     // const       non-const
24
25        return 0;
26
27     } // end main
```

Attempting to invoke non-**`const`** member function on **`const`** object results in compiler error

Attempting to invoke non-**`const`** member function on **`const`** object results in compiler error even if function does not modify object

```
d:\cpphtp4_examples\ch07\fig07_01\fig07_01.cpp(16) : error C2662:
   'setHour' : cannot convert 'this' pointer from 'const class Time'
   to 'class Time &'
        Conversion loses qualifiers
d:\cpphtp4_examples\ch07\fig07_01\fig07_01.cpp(23) : error C2662:
   'printStandard' : cannot convert 'this' pointer from 'const class
   Time' to 'class Time &'
        Conversion loses qualifiers
```

Pointers to object

In many applications, it is advantageous to use pointers to objects

```
class X
{ public:
    int data;
};
int main()
{ X* p = new X;
  (*p).data = 22; // equivalent to: p->data = 22;
  cout << "(*p).data = " << (*p).data << " = " << p->data << endl;
  p->data = 44;
  cout << " p->data = " << (*p).data << " = " << p->data << endl;
}
```

```
(*p).data = 22 = 22
p->data = 44 = 44
```

Since `p` is a pointer to an `X` object, `*p` is an `X` object, and `(*p).data` accesses its public member data. Note that parentheses are required in the expression `(*p).data` because the direct member selection operator " . " has higher precedence than the dereferencing operator " * ".
The two notations

`(*p).data`

`p->data`

have the same meaning. When working with pointers, the "arrow" symbol "-> " is preferred because it is simpler and it suggests "the thing to which p points."

Static data member

Sometimes a single value for a data member applies to all members of the class.

In this case, it would be inefficient to store the same value in every object of the class. That can be avoided by declaring the data member to be `static`. This is done by including the `static` keyword at the beginning of the variable's declaration. It also requires that the variable be defined globally.

So the syntax looks like this:

```
class X
{ public:
  static int n; // declaration of n as a static data member
};
int X::n = 0; // definition of n
```

Static variables are automatically initialized to 0, so the explicit initialization in the definition is unnecessary unless you want it to have a non-zero initial value.

A `static` data member

```
class Widget
{ public:
Widget() { ++count; }
~Widget() { --count; }
static int count;
};

int Widget::count = 0;

int main()
{ Widget w, x;
     cout << "Now there are " << w.count << " widgets.\n";
 { Widget w, x, y, z;
     cout << "Now there are << w.count << " widgets.\n";
 }
     cout << "Now there are "<< w.count << " widgets.\n";
     Widget y;
     cout << "Now there are "<< w.count << " widgets.\n";
}
```

```
Now there are 2 widgets.
Now there are 6 widgets.
Now there are 2 widgets.
Now there are 3 widgets.
```

Notice how four widgets are created inside the inner block, and then they are destroyed when program control leaves that block, reducing the global number of widgets from 6 to 2.
A static data member is like an ordinary global variable: only one copy of the variable exists no matter how many instances of the class exist. The main difference is that it is a data member of the class, and so may be private .

A `static` data member that is `private`

```
class Widget
{ public:
Widget() { ++count; }
~Widget() { --count; }
int numWidgets() { return count; }
private:
static int count;
};

int Widget::count = 0;

int main()
{ Widget w, x;
    cout << "Now there are " << w.numWidgets() << " widgets.\n";
{ Widget w, x, y, z;
    cout << "Now there are " << w.numWidgets() << " widgets.\n";
}
   cout << "Now there are " << w.numWidgets() << " widgets.\n";
    Widget y;
   cout << "Now there are " << w.numWidgets() << " widgets.\n";
}
```

Now that the static variable count is private→we need the access function numWidgets() to read count in main() .

`friend` Functions and `friend` Classes

- **`friend`** function
  - Defined outside class's scope
  - Right to access non-public members
- Declaring **`friend`**s
  - Function
    - Precede function prototype with keyword **`friend`**
  - All member functions of class **`ClassTwo`** as **`friend`**s of class **`ClassOne`**
    - Place declaration of form

      ```
      friend class ClassTwo;
      ```

      in **`ClassOne`** definition

`friend` Functions and `friend` Classes

- Properties of friendship
  - Friendship granted, not taken
    - Class **`B friend`** of class **`A`**
      - Class **`A`** must explicitly declare class **`B friend`**
    - Not symmetric
      - Class **`B friend`** of class **`A`**
      - Class **`A`** not necessarily **`friend`** of class **`B`**
    - Not transitive
      - Class **`A friend`** of class **`B`**
      - Class **`B friend`** of class **`C`**
      - Class **`A`** not necessarily **`friend`** of Class **`C`**

`friend` Functions and `friend` Classes

```
1       // Fig. 7.11: fig07_11.cpp
2       // Friends can access private members of a class.
3       #include <iostream>
4
5       using std::cout;
6       using std::endl;
7
8       // Count class definition
9       class Count {
10        friend void setX( Count &, int ); // friend declaration
11
12    public:
13
14       // constructor
15       Count()
16          : x( 0 )  // initialize x to 0
17       {
18          // empty body
19
20       } // end Count constructor
21
```

Precede function prototype with keyword **`friend`**.

`friend` Functions and `friend` Classes

```
22       // output x
23       void print() const
24       {
25          cout << x << endl;
26
27       } // end function print
28
29    private:
30       int x;  // data member
31
32    }; // end class Count
33
34    // function setX can modify private data of Count
35    // because setX is declared as a
36    void setX( Count &c, int val )
37    {
38       c.x = val;  // legal: setX is a friend of Count
39
40    } // end function setX
41
```

Pass **Count** object since C-style, standalone function

Since **setX friend** of **Count**, can access and modify **private** data member **x**.

`friend` Functions and `friend` Classes

```
42    int main()
43    {
44       Count counter;        // create Count object
45
46       cout << "counter.x after instantiat
47       counter.print();
48
49       setX( counter, 8 );  // set x with a friend
50
51       cout << "counter.x after call to setX friend function: ";
52       counter.print();
53
54       return 0;
55
56    } // end main
```

Use **`friend`** function to access and modify **`private`** data member **`x`**.

```
counter.x after instantiation: 0
counter.x after call to setX friend function: 8
```

`friend` Functions and `friend` Classes

```
1     // Fig. 7.12: fig07_12.cpp
2     // Non-friend/non-member functions cannot access
3     // private data of a class.
4     #include <iostream>
5
6     using std::cout;
7     using std::endl;
8
9     // Count class definition
10    // (note that there is no friendship declaration)
11    class Count {
12
13    public:
14
15       // constructor
16       Count()
17          : x( 0 )  // initialize x to 0
18       {
19          // empty body
20
21       } // end Count constructor
22
```

`friend` Functions and `friend` Classes

```
23       // output x
24       void print() const
25       {
26          cout << x << endl;
27
28       } // end function print
29
30    private:
31       int x;  // data member
32
33    }; // end class Count
34
35    // function tries to modify pr
36    // but cannot because function
37    void cannotSetX( Count &c, int val )
38    {
39       c.x = val;  // ERROR: cannot access private member in Count
40
41    } // end function cannotSetX
42
43    int main()
44    {
45       Count counter;             // create Count object
46
47       cannotSetX( counter, 3 ); // cannotSetX is not a friend
48
49       return 0;
50
51    } // end main
```

Attempting to modify **`private`** data member from non-**`friend`** function results in error.

`friend` Functions and `friend` Classes

```
23       // output x
24       void print() const
25       {
26          cout << x << endl;
27
28       } // end function print
29
30    private:
31       int x;  // data member
32
33    }; // end class Count
34
35    // function tries to modify private data of Count,
36    // but cannot because function is not a friend of Count
37    void cannotSetX( Count &c, int val )
38    {
39       c.x = val;  // ERROR: cannot access private member in Count
40
41    } // end function cannotSetX
```

```
D:\cpphtp4_examples\ch07\Fig07_12\Fig07_12.cpp(39) : error C2248:
   'x' : cannot access private member declared in class 'Count'
         D:\cpphtp4_examples\ch07\Fig07_12\Fig07_12.cpp(31) :
            see declaration of 'x'
```

```
47       cannotSetX( counter, 3 ); // cannotSetX is not a friend
48
49       return 0;
50
51    } // end main
```

Attempting to modify **`private`** data member from non-**`friend`** function results in error.

Using the `this` Pointer

- **`this`** pointer
  - Allows object to access own address
  - Not part of object itself
    - Implicit argument to non-**`static`** member function call
  - Implicitly reference member data and functions
- Type of **`this`** pointer depends on
  - Type of object
  - Whether member function is **`const`**
  - In non-**`const`** member function of **`Employee`**
    - **`this`** has type **`Employee * const`**

    Constant pointer to non-constant **`Employee`** object
  - In **`const`** member function of **`Employee`**
    - **`this`** has type **`const Employee * const`**

    Constant pointer to constant **`Employee`** object

Using the `this` Pointer

```
1       // Fig. 7.13: fig07_13.cpp
2       // Using the this pointer to refer to object members.
3       #include <iostream>
4
5       using std::cout;
6       using std::endl;
7
8       class Test {
9
10    public:
11       Test( int = 0 );    // default constructor
12       void print() const;
13
14    private:
15       int x;
16
17    }; // end class Test
18
19    // constructor
20    Test::Test( int value )
21       : x( value )  // initialize x to value
22    {
23       // empty body
24
25    } // end Test constructor
```

Using the `this` Pointer

```
26
27    // print x using implicit and explicit this poi
28    // parentheses around *this required
29    void Test::print() const
30    {
31       // implicitly use this pointer to access member
32       cout << "        x = " << x;
33
34       // explicitly use this pointer to access member x
35       cout << "\n  this->x = " << this->x;
36
37       // explicitly use dereferenced this pointer and
38       // the dot operator to access member x
39       cout << "\n(*this).x = " << ( *this ).x << endl;
40
41    } // end function print
42
43    int main()
44    {
45       Test testObject( 12 );
46
47       testObject.print();
48
49       return 0;
50
51    } // end main
```

Implicitly use **this** pointer; only specify name of data member (**x**).

Explicitly use **this** pointer with arrow operator

Explicitly use **this** pointer; dereference **this** pointer first, then use dot operator

```
        x = 12
  this->x = 12
(*this).x = 12
```

Using the `this` Pointer

Cascaded member function calls

- Multiple functions invoked in same statement
- Function returns reference pointer to same object

```
{ return *this; }
```

- Other functions operate on that pointer
- Functions that do not return references must be called last

Using the `this` Pointer

```
1       // Fig. 7.14: time6.h
2       // Cascading member function calls.
3
4       // Time class definition.
5       // Member functions defined in time6.cpp.
6       #ifndef TIME6_H
7       #define TIME6_H
8
9       class Time {
10
11    public:
12       Time( int = 0, int = 0, int = 0 );
13
14       // set functions
15       Time &setTime( int, int, int ); // set hour, minute, second
16       Time &setHour( int );    // set hour
17       Time &setMinute( int );  // set minute
18       Time &setSecond( int );  // set second
19
20       // get functions (normally declared const)
21       int getHour() const;     // return hour
22       int getMinute() const;   // return minute
23       int getSecond() const;   // return second
24
```

Set functions return reference to **`Time`** object to enable cascaded member function calls.

Using the `this` Pointer

```
25       // print functions (normally declared const)
26       void printUniversal() const;  // print universal time
27       void printStandard() const;   // print standard time
28
29    private:
30       int hour;     // 0 - 23 (24-hour clock format)
31       int minute;   // 0 - 59
32       int second;   // 0 - 59
33
34    }; // end class Time
35
36    #endif
```

Using the `this` Pointer

```
1     // Fig. 7.15: time6.cpp
2     // Member-function definitions for Time class.
3     #include <iostream>
4
5     using std::cout;
6
7     #include <iomanip>
8
9     using std::setfill;
10    using std::setw;
11
12    #include "time6.h"  // Time class definition
13
14    // constructor function to initialize private data;
15    // calls member function setTime to set variables;
16    // default values are 0 (see class definition)
17    Time::Time( int hr, int min, int sec )
18    {
19       setTime( hr, min, sec );
20
21    } // end Time constructor
22
```

Using the `this` Pointer

```
23    // set values of hour, minute, and second
24    Time &Time::setTime( int h, int m, int s )
25    {
26       setHour( h );
27       setMinute( m );
28       setSecond( s );
29
30       return *this;   // enables cascading
31
32    } // end function setTime
33
34    // set hour value
35    Time &Time::setHour( int h )
36    {
37       hour = ( h >= 0 && h < 24 ) ?
38
39       return *this;   // enables cascading
40
41    } // end function setHour
42
```

Return ***this** as reference to enable cascaded member function calls

Return ***this** as reference to enable cascaded member function calls

Using the `this` Pointer

```
43    // set minute value
44    Time &Time::setMinute( int m )
45    {
46       minute = ( m >= 0 && m < 60 ) ? m : 0;
47
48       return *this;    // enables cascading
49
50    } // end function setMinute
51
52    // set second value
53    Time &Time::setSecond( int s )
54    {
55       second = ( s >= 0 && s < 60 ) ? s : 0;
56
57       return *this;    // enables cascading
58
59    } // end function setSecond
60
61    // get hour value
62    int Time::getHour() const
63    {
64       return hour;
65
66    } // end function getHour
67
```

Return ***this** as reference to enable cascaded member function calls

Return ***this** as reference to enable cascaded member function calls

Using the `this` Pointer

```
68    // get minute value
69    int Time::getMinute() const
70    {
71       return minute;
72
73    } // end function getMinute
74
75    // get second value
76    int Time::getSecond() const
77    {
78       return second;
79
80    } // end function getSecond
81
82    // print Time in universal format
83    void Time::printUniversal() const
84    {
85       cout << setfill( '0' ) << setw( 2 ) << hour << ":"
86            << setw( 2 ) << minute << ":"
87            << setw( 2 ) << second;
88
89    } // end function printUniversal
90
91    // print Time in standard format
92    void Time::printStandard() const
93    {
94       cout << ( ( hour == 0 || hour == 12 ) ? 12 : hour % 12 )
95            << ":" << setfill( '0' ) << setw( 2 ) << minute
96            << ":" << setw( 2 ) << second
97            << ( hour < 12 ? " AM" : " PM" );
98
99    } // end function printStandard
```

```
1   // Fig. 7.16: fig07_16.cpp
2   // Cascading member function calls with the this pointer.
3   #include <iostream>
4
5   using std::cout;
6   using std::endl;
7
8   #include "time6.h"  // Time class definition
9
10  int main()
11  {
12     Time t;
13
14     // cascaded function calls
15     t.setHour( 18 ).setMinute( 30 ).setSe
16
17     // output time in universal and standard formats
18     cout << "Universal time: ";
19     t.printUniversal();
20
21     cout << "\nStandard time: ";
22     t.printStandard();
23
24     cout << "\n\nNew standard time: ";
25
26     // cascaded function calls
27     t.setTime( 20, 20, 20 ).printStandard();
28
29     cout << endl;
30
31     return 0;
32
33  } // end main
```

Cascade member function calls; recall dot operator associates from left to right

Function call to **printStandard** must appear last; **printStandard** does not return reference to **t**

```
Universal time: 18:30:22
Standard time: 6:30:22 PM

New standard time: 8:20:20 PM
```

Esercitazione 8

Exercise 1

- Implement a Matrix class for 2-by-2 matrices

$$\begin{bmatrix} a & b \\ c & d \end{bmatrix}$$

- Include a default constructor, a copy constructor, an `inverse()` function that returns the inverse of the matrix, a `det()` function that returns the determinant of the matrix, a Boolean function `isSingular()` that returns 1 or 0 according to whether the determinant is zero, and a `print()` function that returns the elements of the matrix (implement both the .h and .cpp macros)
- Implement also a macro that uses the class

```
Execution example:
./usaMatrix
Matrix elements are:
1 2
3 4
Determinant of the matrix: -2
Is it singular?1
Copy the matrix and apply inversion via copy constructor
Copy Matrix elements are:
1 2
3 4
After inversion Matrix elements are:
1 2
3 4
```

Operator Overloading

Introduction

- C++ includes a rich store of 45 operators. These operators are defined automatically for the fundamental types (int , float , etc.).
- When you define a class, you are actually creating a new type.
- Most of the C++ operators can be overloaded to apply to your

Op.	Name	Prec.	Assoc.	Arity	Ovrldbl.	Example
`::`	Global scope resolution	17	Right	Unary	No	`::x`
`::`	Class scope resolution	17	Left	Binary	No	`X::x`
`.`	Direct member selection	16	Left	Binary	No	`s.len`
`->`	Indirect member selection	16	Left	Binary	Yes	`p->len`
`[]`	Subscript	16	Left	Binary	Yes	`a[i]`
`()`	Function call	16	Left	n/a	Yes	`rand()`
`()`	Type construction	16	Left	n/a	Yes	`int(ch)`
`++`	Post-increment	16	Right	Unary	Yes	`n++`
`--`	Post-decrement	16	Right	Unary	Yes	`n--`
`sizeof`	Size of object or type	15	Right	Unary	No	`sizeof(a)`
`++`	Pre-increment	15	Right	Unary	Yes	`++n`
`--`	Pre-decrement	15	Right	Unary	Yes	`--n`
`~`	Bitwise complement	15	Right	Unary	Yes	`~s`
`!`	Logical NOT	15	Right	Unary	Yes	`!p`
`+`	Unary plus	15	Right	Unary	Yes	`+n`
`-`	Unary minus	15	Right	Unary	Yes	`-n`
`*`	Dereference	15	Right	Unary	Yes	`*p`
`&`	Address	15	Right	Unary	Yes	`&x`
`new`	Allocation	15	Right	Unary	Yes	`new p`
`delete`	Deallocation	15	Right	Unary	Yes	`delete p`
`()`	Type conversion	15	Right	Binary	Yes	`int(ch)`
`.*`	Direct member selection	14	Left	Binary	No	`x.*q`
`->*`	Indirect member selection	14	Left	Binary	Yes	`p->q`
`*`	Multiplication	13	Left	Binary	Yes	`m*n`
`/`	Division	13	Left	Binary	Yes	`m/n`
`%`	Remainder	13	Left	Binary	Yes	`m%n`
`+`	Addition	12	Left	Binary	Yes	`m + n`
`-`	Subtraction	12	Left	Binary	Yes	`m - n`
`<<`	Bit shift left	11	Left	Binary	Yes	`cout << n`
`>>`	Bit shift right	11	Left	Binary	Yes	`cin >> n`
`<`	Less than	10	Left	Binary	Yes	`x < y`
`<=`	Less than or equal to	10	Left	Binary	Yes	`x <= y`
`>`	Greater than	10	Left	Binary	Yes	`x > y`
`>=`	Greater than or equal to	10	Left	Binary	Yes	`x >= y`
`==`	Equal to	9	Left	Binary	Yes	`x == y`
`!=`	Not equal to	9	Left	Binary	Yes	`x != y`
`&`	Bitwise AND	8	Left	Binary	Yes	`s&t`
`^`	Bitwise XOR	7	Left	Binary	Yes	`s^t`
`|=`	Bitwise OR assignment	2	Right	Binary	Yes	`s |= mask`
`<<=`	Bit shift left assignment	2	Right	Binary	Yes	`s <<= 1`
`>>=`	Bit shift right assignment	2	Right	Binary	Yes	`s >>= 1`
`,`	Comma	0	Left	Binary	Yes	`++m,--n`

Introduction

- Use operators with objects (operator overloading)
  - Clearer than function calls for certain classes
- Operator sensitive to context
- Examples:
  - `<<` Stream insertion, bitwise left-shift
  - `+` Performs arithmetic on multiple types (integers, floats, etc.)
- Will discuss when to use operator overloading

Fundamentals of Operator Overloading

- Types
  - Built in (**`int`**, **`char`**) or user-defined
  - Can use existing operators with user-defined types
    - Cannot create new operators
- Overloading operators
  - Create a function for the class
  - Name function **`operator`** followed by symbol
    - **`Operator+`** for the addition operator **`+`**

Fundamentals of Operator Overloading

- Using operators on a class object
  - It must be overloaded for that class
    - Exceptions:
    - Assignment operator, **=**
      - Memberwise assignment between objects
    - Address operator, **&**
      - Returns address of object
    - Both can be overloaded
- Overloading provides concise notation

```
object2 = object1.add(object2);
object2 = object2 + object1;
```

Restrictions on Operator Overloading

- Cannot change
  - How operators act on built-in data types
    - I.e., cannot change integer addition
  - Precedence of operator (order of evaluation)
    - Use parentheses to force order-of-operations
  - Associativity (left-to-right or right-to-left)
  - Number of operands
    - **&** is unitary, only acts on one operand
- Cannot create new operators
- Operators must be overloaded explicitly
  - Overloading **+** does not overload **+=**

Restrictions on Operator Overloading

Operators that can be overloaded							
+	-	*	/	%	^	&	|
~	!	=	<	>	+=	-=	*=
/=	%=	^=	&=	|=	<<	>>	>>=
<<=	==	!=	<=	>=	&&	||	++
--	->*	,	->	[]	()	new	delete
new[]	delete[]						

Operators that cannot be overloaded				
.	.*	::	?:	sizeof

Operator Functions As Class Members Vs. As Friend Functions

- Operator functions
  - Member functions
    - Use **`this`** keyword to implicitly get argument
    - Gets left operand for binary operators (like **+**)
    - Leftmost object must be of same class as operator
  - Non member functions
    - Need parameters for both operands
    - Can have object of different class than operator
    - Must be a **`friend`** to access **`private`** or **`protected`** data
  - Called when
    - Left operand of binary operator of same class
    - Single operand of unitary operator of same class

Operator Functions As Class Members Vs. As Friend Functions

- Overloaded **<<** operator
  - Left operand of type **`ostream &`**
    - Such as **`cout`** object in **`cout << classObject`**
  - Similarly, overloaded **>>** needs **`istream &`**
  - Thus, both must be non-member functions

Operator Functions As Class Members Vs. As Friend Functions

- Commutative operators
  - May want **+** to be commutative
    - So both "**`a + b`**" and "**`b + a`**" work
  - Suppose we have two different classes
  - Overloaded operator can only be member function when its class is on left
  - **`HugeIntClass + Long int`**
  - Can be member function
- When other way, need a non-member overload function
  - **`Long int + HugeIntClass`**

Overloading Stream-Insertion and Stream-Extraction Operators

- **<<** and **>>**
  - Already overloaded to process each built-in type
  - Can also process a user-defined class
- Example program
  - Class **`PhoneNumber`**
    - Holds a telephone number
  - Print out formatted number automatically
    - **`(123) 456-7890`**

```
1     // Fig. 8.3: fig08_03.cpp
2     // Overloading the stream-insertion and
3     // stream-extraction operators.
4     #include <iostream>
5
6     using std::cout;
7     using std::cin;
8     using std::endl;
9     using std::ostream;
10    using std::istream;
11
12    #include <iomanip>
13
14    using std::setw;
15
16    // PhoneNumber class definition
17    class PhoneNumber {
18       friend ostream &operator<<( ostream&, const PhoneNumber & );
19       friend istream &operator>>( istream&, PhoneNumber & );
20
21    private:
22       char areaCode[ 4 ];  // 3-digit area code and null
23       char exchange[ 4 ];  // 3-digit exchange and null
24       char line[ 5 ];      // 4-digit line and null
25
26    }; // end class PhoneNumber
```

Notice function prototypes for overloaded operators **>>** and **<<**

They must be non-member **friend** functions, since the object of class **Phonenumber** appears on the right of the operator.

```
cin << object
cout >> object
```

```
27
28    // overloaded stream-insertion operator; cannot be
29    // a member function if we would like to invoke it with
30    // cout << somePhoneNumber;
31    ostream &operator<<( ostream &output, const PhoneNumber &num )
32    {
33       output << "(" << num.areaCode << ") "
34              << num.exchange << "-" << num.line;
35
36       return output;     // enables cout << a << b << c;
37
38    } // end function operator<<
39
40    // overloaded stream-extraction operator; cannot be
41    // a member function if we would like to invoke it with
42    // cin >> somePhoneNumber;
43    istream &operator>>( istream &input, PhoneNumber &num )
44    {
45       input.ignore();                      // skip (
46       input >> setw( 4 ) >> num.areaCode; // input area code
47       input.ignore( 2 );                   // skip ) and space
48       input >> setw( 4 ) >> num.exchange; // input exchange
49       input.ignore();                      // skip dash (-)
50       input >> setw( 5 ) >> num.line;     // input line
51
52       return input;      // enables cin >> a >> b >> c;
53
54    } // end function operator>>
```

```
27
28    // overloaded stream-insertion operator; cannot be
29    // a member function if we would like to invoke it with
30    // cout << somePhoneNumber;
31    ostream &operator<<( ostream &output, const PhoneNumber &num )
32    {
33       output << "(" << num.areaCode << ") "
34              << num.exchange << "-" << num.line;
35
36       return output;      // enables cout << a << b << c;
37
38    } // end function operator<<
39
40    // overloaded stream-extractio
41    // a member function if we wou
42    // cin >> somePhoneNumber;
43    istream &operator>>( istream &
44    {
45       input.ignore();                    // skip (
46       input >> setw( 4 ) >> num.area
47       input.ignore( 2 );
48       input >> setw( 4 ) >> num.exchange; // input exchange
49       input.ignore();                    // skip dash (-)
50       input >> setw( 5 ) >> num.line
51
52       return input;       // enables
53
54    } // end function operator>>
```

The expression:
cout << phone;
is interpreted as the function call:
operator<<(cout, phone);

output is an alias for **cout**

This allows objects to be cascaded.
cout << phone1 << phone2;
first calls
operator<<(cout, phone1), and returns **cout**.

Next, **cout << phone2** executes.

ignore() skips specified number of characters from input (1 by default)

Stream manipulator **setw** restricts number of characters read. **setw(4)** allows 3 characters to be read, leaving room for the null character.

```
55
56    int main()
57    {
58       PhoneNumber phone; // create object phone
59
60       cout << "Enter phone number in the form (123) 456-7890:\n";
61
62       // cin >> phone invokes operator>> by implicitly issuing
63       // the non-member function call operator>>( cin, phone )
64       cin >> phone;
65
66       cout << "The phone number entered was: " ;
67
68       // cout << phone invokes operator<< by implicitly issuing
69       // the non-member function call operator<<( cout, phone )
70       cout << phone << endl;
71
72       return 0;
73
74    } // end main
```

```
Enter phone number in the form (123) 456-7890:
(800) 555-1212
The phone number entered was: (800) 555-1212
```

Overloading Unary Operators

- Overloading unary operators
  - Non-**`static`** member function, no arguments
  - Non-member function, one argument
    - Argument must be class object or reference to class object
  - Remember, **`static`** functions only access **`static`** data

Overloading Unary Operators

- Upcoming example
  - Overload `!` to test for empty string
  - If non-**`static`** member function, needs no arguments
    - `!s` becomes `s.operator!()`

```
class String {
public:
   bool operator!() const;
   ...
};
```

  - If non-member function, needs one argument
    - `s!` becomes `operator!(s)`

```
class String {
  friend bool operator!( const String & )
  ...
}
```

Overloading Binary Operators

- Overloading binary operators
  - Non-**`static`** member function, one argument
  - Non-member function, two arguments
- One argument must be class object or reference
  - Upcoming example
  - If non-**`static`** member function, needs one argument

```
class String {
  public:
    const String &operator+=( const String & );
     …
    };
```

  - **`y += z`** equivalent to **`y.operator+=( z )`**

Overloading Binary Operators

- Upcoming example
- If non-member function, needs two arguments
- Example:

```
class String {
   friend const String &operator+=(
                  String &, const String & );
   ...
};
```

  - **`y += z`** equivalent to **`operator+=( y, z )`**

Case Study: Array class

- Arrays in C++
  - No range checking
  - Cannot be compared meaningfully with **==**
  - No array assignment (array names **const** pointers)
  - Cannot input/output entire arrays at once
    - One element at a time
- Example:Implement an **Array** class with
  - Range checking
  - Array assignment
  - Arrays that know their size
  - Outputting/inputting entire arrays with **<<** and **>>**
  - Array comparisons with **==** and **!=**

Case Study: Array class

- Copy constructor
  - Used whenever copy of object needed
    - Passing by value (return value or parameter)
    - Initializing an object with a copy of another

      `Array newArray( oldArray );`

      `newArray` copy of **`oldArray`**
- Prototype for class **`Array`**
  - **`Array( const Array & );`**
  - *Must* take reference
    - Otherwise, pass by value
    - Tries to make copy by calling copy constructor…
    - Infinite loop

Array class

```
1   // Fig. 8.4: array1.h
2   // Array class for storing arrays of integers.
3   #ifndef ARRAY1_H
4   #define ARRAY1_H
5
6   #include <iostream>
7
8   using std::ostream;
9   using std::istream;
10
11  class Array {
12     friend ostream &operator<<( ostream &, const Array & );
13     friend istream &operator>>( istream &, Array & );
14
15  public:
16     Array( int = 10 );          // default co
17     Array( const Array & );     // copy constructor
18     ~Array();                   // destructor
19     int getSize() const;        // return size
20
21     // assignment operator
22     const Array &operator=( const Array & );
23
24     // equality operator
25     bool operator==( const Array & ) const;
26
```

Most operators overloaded as member functions (except **<<** and **>>**, which must be non-member functions).

Prototype for copy constructor

Array class

```
27       // inequality operator; returns opposite of == operator
28       bool operator!=( const Array &right ) const
29       {
30          return ! ( *this == right ); // invokes Array::operator==
31
32       } // end function operator!=
33
34       // subscript operator for non-con
35       int &operator[]( int );
36
37       // subscript operator for const objects returns rvalue
38       const int &operator[]( int ) const;
39
40    private:
41       int size; // array size
42       int *ptr; // pointer to first element of array
43
44    }; // end class Array
45
46    #endif
```

!= operator simply returns opposite of **==** operator. Thus, only need to define the **==** operator.

Array class

```
1     // Fig 8.5: array1.cpp
2     // Member function definitions for class Array
3     #include <iostream>
4
5     using std::cout;
6     using std::cin;
7     using std::endl;
8
9     #include <iomanip>
10
11    using std::setw;
12
13    #include <new>        // C++ standard "new" operator
14
15    #include <cstdlib>    // exit function prototype
16
17    #include "array1.h"   // Array class definition
18
19    // default constructor for class Array (default size 10)
20    Array::Array( int arraySize )
21    {
22       // validate arraySize
23       size = ( arraySize > 0 ? arraySize : 10 );
24
25       ptr = new int[ size ]; // create space for array
26
```

Array class

```
27       for ( int i = 0; i < size; i++ )
28          ptr[ i ] = 0;           // initialize array
29
30    } // end Array default constructor
31
32    // copy constructor for class Array;
33    // must receive a reference to prevent
34    Array::Array( const Array &arrayToCopy
35       : size( arrayToCopy.size )
36    {
37       ptr = new int[ size ]; // create space for array
38
39       for ( int i = 0; i < size; i++ )
40          ptr[ i ] = arrayToCopy.ptr[ i ];  // copy into object
41
42    } // end Array copy constructor
43
44    // destructor for class Array
45    Array::~Array()
46    {
47       delete [] ptr;  // reclaim array space
48
49    } // end destructor
50
```

We must declare a new integer array so the objects do not point to the same memory.

Array class

```
51    // return size of array
52    int Array::getSize() const
53    {
54       return size;
55
56    } // end function getSize
57
58    // overloaded assignment operato
59    // const return avoids: ( a1 = a2 ) = a3
60    const Array &Array::operator=( const Array &right )
61    {
62       if ( &right != this ) {  // check for self-assignment
63
64          // for arrays of different sizes, deallocate original
65          // left-side array, then allocate new left-side array
66          if ( size != right.size ) {
67             delete [] ptr;          // reclaim space
68             size = right.size;      // resize this object
69             ptr = new int[ size ]; // create space for array copy
70
71          } // end inner if
72
73          for ( int i = 0; i < size; i++ )
74             ptr[ i ] = right.ptr[ i ];  // copy array into object
75
76       } // end outer if
```

Want to avoid self-assignment.

Array class

```
77
78       return *this;   // enables x = y = z, for example
79
80    } // end function operator=
81
82    // determine if two arrays are equal and
83    // return true, otherwise return false
84    bool Array::operator==( const Array &right ) const
85    {
86       if ( size != right.size )
87          return false;    // arrays of different sizes
88
89       for ( int i = 0; i < size; i++ )
90
91          if ( ptr[ i ] != right.ptr[ i ] )
92             return false; // arrays are not equal
93
94       return true;         // arrays are equal
95
96    } // end function operator==
97
```

Array class

```
98    // overloaded subscript operator for non-const Arrays
99    // reference return creates an lvalue
100 int &Array::operator[]( int subscript )
101 {
102    // check for subscript out of range error
103    if ( subscript < 0 || subscript >= size ) {
104       cout << "\nError: Subscript " << subscript
105            << " out of range" << endl;
106
107       exit( 1 );  // terminate program; subscript out of range
108
109    } // end if
110
111    return ptr[ subscript ]; // reference return
112
113 } // end function operator[]
114
```

integers1[5] calls **integers1.operator[](5)**

exit() (header **<cstdlib>**) ends the program.

```
115 // overloaded subscript operator for const Arrays
116 // const reference return creates an rvalue
117 const int &Array::operator[]( int subscript ) const
118 {
119    // check for subscript out of range error
120    if ( subscript < 0 || subscript >= size ) {
121       cout << "\nError: Subscript " << subscript
122            << " out of range" << endl;
123
124       exit( 1 );  // terminate program; subscript out of range
125
126    } // end if
127
128    return ptr[ subscript ]; // const reference return
129
130 } // end function operator[]
131
132 // overloaded input operator for class Array;
133 // inputs values for entire array
134 istream &operator>>( istream &input, Array &a )
135 {
136    for ( int i = 0; i < a.size; i++ )
137       input >> a.ptr[ i ];
138
139    return input;   // enables cin >> x >> y;
140
141 } // end function
```

Array class

```
142
143 // overloaded output operator for class Array
144 ostream &operator<<( ostream &output, const Array &a )
145 {
146    int i;
147
148    // output private ptr-based array
149    for ( i = 0; i < a.size; i++ ) {
150       output << setw( 12 ) << a.ptr[ i ];
151
152       if ( ( i + 1 ) % 4 == 0 ) // 4 numbers per row of output
153          output << endl;
154
155    } // end for
156
157    if ( i % 4 != 0 )  // end last line of output
158       output << endl;
159
160    return output;   // enables cout << x << y;
161
162 } // end function operator<<
```

Array class

```
1     // Fig. 8.6: fig08_06.cpp
2     // Array class test program.
3     #include <iostream>
4
5     using std::cout;
6     using std::cin;
7     using std::endl;
8
9     #include "array1.h"
10
11    int main()
12    {
13       Array integers1( 7 );  // seven-element Array
14       Array integers2;       // 10-element Array by default
15
16       // print integers1 size and contents
17       cout << "Size of array integers1 is "
18            << integers1.getSize()
19            << "\nArray after initialization:\n" << integers1;
20
21       // print integers2 size and contents
22       cout << "\nSize of array integers2 is "
23            << integers2.getSize()
24            << "\nArray after initialization:\n" << integers2;
25
```

Array class

```
26       // input and print integers1 and integers2
27       cout << "\nInput 17 integers:\n";
28       cin >> integers1 >> integers2;
29
30       cout << "\nAfter input, the arrays contain:\n"
31            << "integers1:\n" << integers1
32            << "integers2:\n" << integers2;
33
34       // use overloaded inequality (!=) operator
35       cout << "\nEvaluating: integers1 != integers2\n";
36
37       if ( integers1 != integers2 )
38          cout << "integers1 and integers2 are not equal\n";
39
40       // create array integers3 using integers1 as an
41       // initializer; print size and contents
42       Array integers3( integers1 );  // calls copy constructor
43
44       cout << "\nSize of array integers3 is "
45            << integers3.getSize()
46            << "\nArray after initialization:\n" << integers3;
47
```

```
48       // use overloaded assignment (=) operator
49       cout << "\nAssigning integers2 to integers1:\n";
50       integers1 = integers2;  // note target is smaller
51
52       cout << "integers1:\n" << integers1
53            << "integers2:\n" << integers2;
54
55       // use overloaded equality (==) operator
56       cout << "\nEvaluating: integers1 == integers2\n";
57
58       if ( integers1 == integers2 )
59          cout << "integers1 and integers2 are equal\n";
60
61       // use overloaded subscript operator to create rvalue
62       cout << "\nintegers1[5] is " << integers1[ 5 ];
63
64       // use overloaded subscript operator to create lvalue
65       cout << "\n\nAssigning 1000 to integers1[5]\n";
66       integers1[ 5 ] = 1000;
67       cout << "integers1:\n" << integers1;
68
69       // attempt to use out-of-range subscript
70       cout << "\nAttempt to assign 1000 to integers1[15]" << endl;
71       integers1[ 15 ] = 1000;  // ERROR: out of range
72
73       return 0;
74
75    } // end main
```

```
Size of array integers1 is 7
Array after initialization:
           0           0           0           0
           0           0           0

Size of array integers2 is 10
Array after initialization:
           0           0           0           0
           0           0           0           0
           0           0

Input 17 integers:
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

After input, the arrays contain:
integers1:
           1           2           3           4
           5           6           7
integers2:
           8           9          10          11
          12          13          14          15
```

```
Evaluating: integers1 != integers2
integers1 and integers2 are not equal

Size of array integers3 is 7
Array after initialization:
           1           2           3           4
           5           6           7

Assigning integers2 to integers1:
integers1:
           8           9          10          11
          12          13          14          15
          16          17
integers2:
           8           9          10          11
          12          13          14          15
          16          17

Evaluating: integers1 == integers2
integers1 and integers2 are equal

integers1[5] is 13
```

```
Assigning 1000 to integers1[5]
integers1:
          8           9          10          11
         12        1000          14          15
         16          17

Attempt to assign 1000 to integers1[15]

Error: Subscript 15 out of range
```

Converting between Types

- Casting
  - Traditionally, cast integers to floats, etc.
  - May need to convert between user-defined types
- Cast operator (conversion operator)
  - Convert from
    - One class to another
    - Class to built-in type (**`int`**, **`char`**, etc.)
  - Must be non-**`static`** member function
    - Cannot be **`friend`**
  - Do not specify return type
    - Implicitly returns type to which you are converting

Converting between Types

- Example
  - Prototype

```
A::operator char *() const;
```

    - Casts class **A** to a temporary **char ***
    - **(char *)s** calls **s.operator char*()**
- Also
  - **A::operator int() const;**
  - **A::operator OtherClass() const;**

Converting between Types

- Casting can prevent need for overloading
  - Suppose class **`String`** can be cast to **`char *`**
  - **`cout << s; // s is a String`**
    - Compiler implicitly converts **`s`** to **`char *`**
    - Do not have to overload **`<<`**
  - Compiler can only do 1 cast

Case Study: A `String` Class

- Build class **`String`**
  - String creation, manipulation
  - Class **`string`** in standard library
- Conversion constructor
  - Single-argument constructor
  - Turns objects of other types into class objects
    - **`String s1("hi");`**
    - Creates a **`String`** from a **`char *`**
  - Any single-argument constructor is a conversion constructor

String Class

```
1     // Fig. 8.7: string1.h
2     // String class definition.
3     #ifndef STRING1_H
4     #define STRING1_H
5
6     #include <iostream>
7
8     using std::ostream;
9     using std::istream;
10
11    class String {
12       friend ostream &operator<<( ostrea
13       friend istream &operator>>( istrea
14
15    public:
16       String( const char * = "" ); // conversion/default ctor
17       String( const String & );    // copy constructor
18       ~String();                   // destructor
19
20       const String &operator=( const String & );
21       const String &operator+=( const String & );
22
23       bool operator!() const;                    //
24       bool operator==( const String & ) const; //
25       bool operator<( const String & ) const;  //
26
```

Conversion constructor to make a **`String`** from a **`char *`**.

`s1 += s2` interpreted as **`s1.operator+=(s2)`**

Can also concatenate a **`String`** and a **`char *`** because the compiler will cast the **`char *`** argument to a **`String`**. However, it can only do 1 level of casting.

```
27       // test s1 != s2
28       bool operator!=( const String & right ) const
29       {
30          return !( *this == right );
31
32       } // end function operator!=
33
34       // test s1 > s2
35       bool operator>( const String &right ) const
36       {
37          return right < *this;
38
39       } // end function operator>
40
41       // test s1 <= s2
42       bool operator<=( const String &right ) const
43       {
44          return !( right < *this );
45
46       } // end function operator <=
47
48       // test s1 >= s2
49       bool operator>=( const String &right ) const
50       {
51          return !( *this < right );
52
53       } // end function operator>=
```

String Class

```
54
55       char &operator[]( int );                //
56       const char &operator[]( int ) const; //
57
58       String operator()( int, int );          // return a substring
59
60       int getLength() const;                  //
61
62    private:
63       int length;  // string length
64       char *sPtr;  // pointer to start of string
65
66       void setString( const char * );  // utility function
67
68    }; // end class String
69
70    #endif
```

Two overloaded subscript operators, for **const** and non-**const** objects.

Overload the function call operator **()** to return a substring. This operator can have any amount of operands.

String Class

```
1      // Fig. 8.8: string1.cpp
2      // Member function definitions for class String.
3      #include <iostream>
4
5      using std::cout;
6      using std::endl;
7
8      #include <iomanip>
9
10    using std::setw;
11
12    #include <new>         // C++ standard "new" operator
13
14    #include <cstring>     // strcpy and strcat prototypes
15    #include <cstdlib>     // exit prototype
16
17    #include "string1.h"   // String class definition
18
19    // conversion constructor converts char * to String
20    String::String( const char *s )
21       : length( strlen( s ) )
22    {
23       cout << "Conversion constructor: " << s << '\n';
24       setString( s );          // call utility function
25
26    } // end String conversion constructor
```

```
27
28    // copy constructor
29    String::String( const String &copy )
30       : length( copy.length )
31    {
32       cout << "Copy constructor: " << copy.sPtr << '\n';
33       setString( copy.sPtr ); // call utility function
34
35    } // end String copy constructor
36
37    // destructor
38    String::~String()
39    {
40       cout << "Destructor: " << sPtr << '\n';
41       delete [] sPtr;          // reclaim string
42
43    } // end ~String destructor
44
45    // overloaded = operator; avoids self assignment
46    const String &String::operator=( const String &right )
47    {
48       cout << "operator= called\n";
49
50       if ( &right != this ) {          // avoid self assignment
51          delete [] sPtr;               // prevents memory leak
52          length = right.length;        // new String length
53          setString( right.sPtr );      // call utility function
54       }
```

```
55
56       else
57          cout << "Attempted assignment of a String to itself\n";
58
59       return *this;   // enables cascaded assignments
60
61    } // end function operator=
62
63    // concatenate right operand to this object and
64    // store in this object.
65    const String &String::operator+=( const String &right )
66    {
67       size_t newLength = length + right.length;   // new length
68       char *tempPtr = new char[ newLength + 1 ];  // create memory
69
70       strcpy( tempPtr, sPtr );                    // copy sPtr
71       strcpy( tempPtr + length, right.sPtr );  // copy right.sPtr
72
73       delete [] sPtr;       // reclaim old space
74       sPtr = tempPtr;       // assign new array to sPtr
75       length = newLength;  // assign new length to length
76
77       return *this;  // enables cascaded calls
78
79    } // end function operator+=
80
```

String Class

```
81    // is this String empty?
82    bool String::operator!() const
83    {
84       return length == 0;
85
86    } // end function operator!
87
88    // is this String equal to right String?
89    bool String::operator==( const String &right ) const
90    {
91       return strcmp( sPtr, right.sPtr ) == 0;
92
93    } // end function operator==
94
95    // is this String less than right String?
96    bool String::operator<( const String &right ) const
97    {
98       return strcmp( sPtr, right.sPtr ) < 0;
99
100 } // end function operator<
101
```

```
102 // return reference to character in String as lvalue
103 char &String::operator[]( int subscript )
104 {
105    // test for subscript out of range
106    if ( subscript < 0 || subscript >= length ) {
107       cout << "Error: Subscript " << subscript
108            << " out of range" << endl;
109
110       exit( 1 );  // terminate program
111    }
112
113    return sPtr[ subscript ];  // creates lvalue
114
115 } // end function operator[]
116
117 // return reference to character in String as rvalue
118 const char &String::operator[]( int subscript ) const
119 {
120    // test for subscript out of range
121    if ( subscript < 0 || subscript >= length ) {
122       cout << "Error: Subscript " << subscript
123            << " out of range" << endl;
124
125       exit( 1 );  // terminate program
126    }
127
128    return sPtr[ subscript ];  // creates rvalue
129
130 } // end function operator[]
```

String Class

```
131
132 // return a substring beginning at index and
133 // of length subLength
134 String String::operator()( int index, int subLength )
135 {
136    // if index is out of range or substring length < 0,
137    // return an empty String object
138    if ( index < 0 || index >= length || subLength < 0 )
139       return "";  // converted to a String object automatically
140
141    // determine length of substring
142    int len;
143
144    if ( ( subLength == 0 ) || ( index + subLength > length ) )
145       len = length - index;
146    else
147       len = subLength;
148
149    // allocate temporary array for substring and
150    // terminating null character
151    char *tempPtr = new char[ len + 1 ];
152
153    // copy substring into char array and terminate string
154    strncpy( tempPtr, &sPtr[ index ], len );
155    tempPtr[ len ] = '\0';
```

String Class

```
156
157    // create temporary String object containing the substring
158    String tempString( tempPtr );
159    delete [] tempPtr;  // delete temporary array
160
161    return tempString;  // return copy of the temporary String
162
163 } // end function operator()
164
165 // return string length
166 int String::getLength() const
167 {
168    return length;
169
170 } // end function getLenth
171
172 // utility function called by constructors and operator=
173 void String::setString( const char *string2 )
174 {
175    sPtr = new char[ length + 1 ]; // allocate memory
176    strcpy( sPtr, string2 );       // copy literal to object
177
178 } // end function setString
```

String Class

```
179
180  // overloaded output operator
181  ostream &operator<<( ostream &output, const String &s )
182  {
183     output << s.sPtr;
184
185     return output;   // enables cascading
186
187  } // end function operator<<
188
189  // overloaded input operator
190  istream &operator>>( istream &input, String &s )
191  {
192     char temp[ 100 ];   // buffer to store input
193
194     input >> setw( 100 ) >> temp;
195     s = temp;           // use String class assignment operator
196
197     return input;    // enables cascading
198
199  } // end function operator>>
```

String Class

```
1       // Fig. 8.9: fig08_09.cpp
2       // String class test program.
3       #include <iostream>
4
5       using std::cout;
6       using std::endl;
7
8       #include "string1.h"
9
10      int main()
11      {
12         String s1( "happy" );
13         String s2( " birthday" );
14         String s3;
15
16         // test overloaded equality and relational operators
17         cout << "s1 is \"" << s1 << "\"; s2 is \"" << s2
18              << "\"; s3 is \"" << s3 << '\"'
19              << "\n\nThe results of comparing s2 and s1:"
20              << "\ns2 == s1 yields "
21              << ( s2 == s1 ? "true" : "false" )
22              << "\ns2 != s1 yields "
23              << ( s2 != s1 ? "true" : "false" )
24              << "\ns2 >  s1 yields "
25              << ( s2 > s1 ? "true" : "false" )
```

String Class

```
26            << "\ns2 <  s1 yields "
27            << ( s2 < s1 ? "true" : "false" )
28            << "\ns2 >= s1 yields "
29            << ( s2 >= s1 ? "true" : "false" )
30            << "\ns2 <= s1 yields "
31            << ( s2 <= s1 ? "true" : "false" );
32
33      // test overloaded String empty (!) operator
34      cout << "\n\nTesting !s3:\n";
35
36      if ( !s3 ) {
37         cout << "s3 is empty; assigning s1 to s3;\n";
38         s3 = s1;  // test overloaded assignment
39         cout << "s3 is \"" << s3 << "\"";
40      }
41
42      // test overloaded String concatenation operator
43      cout << "\n\ns1 += s2 yields s1 = ";
44      s1 += s2;  // test overloaded concatenation
45      cout << s1;
46
47      // test conversion constructor
48      cout << "\n\ns1 += \" to you\" yields\n";
49      s1 += " to you";  // test conversion constructor
50      cout << "s1 = " << s1 << "\n\n";
```

String Class

```
51
52       // test overloaded function call operator () for substring
53       cout << "The substring of s1 starting at\n"
54            << "location 0 for 14 characters, s1(0, 14), is:\n"
55            << s1( 0, 14 ) << "\n\n";
56
57       // test substring "to-end-of-String" option
58       cout << "The substring of s1 starting at\n"
59            << "location 15, s1(15, 0), is: "
60            << s1( 15, 0 ) << "\n\n";  // 0 is "to end of string"
61
62       // test copy constructor
63       String *s4Ptr = new String( s1 );
64       cout << "\n*s4Ptr = " << *s4Ptr << "\n\n";
65
66       // test assignment (=) operator with self-assignment
67       cout << "assigning *s4Ptr to *s4Ptr\n";
68       *s4Ptr = *s4Ptr;  // test overloaded assignment
69       cout << "*s4Ptr = " << *s4Ptr << '\n';
70
71       // test destructor
72       delete s4Ptr;
73
```

String Class

```
74        // test using subscript operator to create lvalue
75        s1[ 0 ] = 'H';
76        s1[ 6 ] = 'B';
77        cout << "\ns1 after s1[0] = 'H' and s1[6] = 'B' is: "
78             << s1 << "\n\n";
79
80        // test subscript out of range
81        cout << "Attempt to assign 'd' to s1[30] yields:" << endl;
82        s1[ 30 ] = 'd';      // ERROR: subscript out of range
83
84        return 0;
85
86     } // end main
```

String Class

```
Conversion constructor: happy
Conversion constructor:  birthday
Conversion constructor:
s1 is "happy"; s2 is " birthday"; s3 is ""

The results of comparing s2 and s1:
s2 == s1 yields false
s2 != s1 yields true
s2 >  s1 yields false
s2 <  s1 yields true
s2 >= s1 yields false
s2 <= s1 yields true

Testing !s3:
s3 is empty; assigning s1 to s3;
operator= called
s3 is "happy"

s1 += s2 yields s1 = happy birthday

s1 += " to you" yields
Conversion constructor:  to you
Destructor:  to you
  s1 = happy birthday to you
```

The constructor and destructor are called for the temporary **`String`** (converted from the **`char * "to you"`**).

String Class

```
Conversion constructor: happy birthday
Copy constructor: happy birthday
Destructor: happy birthday
The substring of s1 starting at
location 0 for 14 characters, s1(0, 14), is:
happy birthday

Destructor: happy birthday
Conversion constructor: to you
Copy constructor: to you
Destructor: to you
The substring of s1 starting at
location 15, s1(15, 0), is: to you

Destructor: to you
Copy constructor: happy birthday to you

*s4Ptr = happy birthday to you

assigning *s4Ptr to *s4Ptr
operator= called
Attempted assignment of a String to itself
*s4Ptr = happy birthday to you
Destructor: happy birthday to you

s1 after s1[0] = 'H' and s1[6] = 'B' is: Happy Birthday to you

Attempt to assign 'd' to s1[30] yields:
Error: Subscript 30 out of range
```

Overloading ++ and --

- Increment/decrement operators can be overloaded
  - Add 1 to a **`Date`** object, **`d1`**
  - Prototype (member function)
    - **`Date &operator++();`**
    - **`++d1`** same as **`d1.operator++()`**
  - Prototype (non-member)
    - **`Friend Date &operator++( Date &);`**
    - **`++d1`** same as **`operator++( d1 )`**

Overloading ++ and --

- To distinguish pre/post increment
  - Post increment has a dummy parameter
    - **`int`** of **`0`**
  - Prototype (member function)
    - **`Date operator++( int );`**
    - **`d1++`** same as **`d1.operator++( 0 )`**
  - Prototype (non-member)
    - **`friend Date operator++( Data &, int );`**
    - **`d1++`** same as **`operator++( d1, 0 )`**
  - Integer parameter does not have a name
    - Not even in function definition

Overloading ++ and --

- Return values
  - Preincrement
    - Returns by reference (**`Date &`**)
    - lvalue (can be assigned)
  - Postincrement
    - Returns by value
    - Returns temporary object with old value
    - rvalue (cannot be on left side of assignment)
- Decrement operator analogous

Case Study: A `Date` Class

- Example **`Date`** class
  - Overloaded increment operator
    - Change day, month and year
  - Overloaded **`+=`** operator
  - Function to test for leap years
  - Function to determine if day is last of month

```
1   // Fig. 8.10: date1.h
2   // Date class definition.
3   #ifndef DATE1_H
4   #define DATE1_H
5   #include <iostream>
6
7   using std::ostream;
8
9   class Date {
10    friend ostream &operator<<( ostream &, const Date & );
11
12  public:
13     Date( int m = 1, int d = 1, int y = 1
14     void setDate( int, int, int ); // set
15
16     Date &operator++();              // preincrement operator
17     Date operator++( int );          // postincrement operator
18
19     const Date &operator+=( int ); // add days, modify object
20
21     bool leapYear( int ) const;    // is this a leap year?
22     bool endOfMonth( int ) const;  // is this end of month?
23
24  private:
25     int month;
26     int day;
27     int year;
28
29     static const int days[];       // array of days per month
30     void helpIncrement();          // utility function
31
32  }; // end class Date
33
34  #endif
```

Note difference between pre and post increment.

Overloading

```
1     // Fig. 8.11: date1.cpp
2     // Date class member function definitions.
3     #include <iostream>
4     #include "date1.h"
5
6     // initialize static member at file scope;
7     // one class-wide copy
8     const int Date::days[] =
9        { 0, 31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31 };
10
11    // Date constructor
12    Date::Date( int m, int d, int y )
13    {
14       setDate( m, d, y );
15
16    } // end Date constructor
17
18    // set month, day and year
19    void Date::setDate( int mm, int dd, int yy )
20    {
21       month = ( mm >= 1 && mm <= 12 ) ? mm : 1;
22       year = ( yy >= 1900 && yy <= 2100 ) ? yy : 1900;
23
```

```
24       // test for a leap year
25       if ( month == 2 && leapYear( year ) )
26          day = ( dd >= 1 && dd <= 29 ) ? dd : 1;
27       else
28          day = ( dd >= 1 && dd <= days[ month ] ) ? dd : 1;
29
30    } // end function setDate
31
32    // overloaded preincrement operator
33    Date &Date::operator++()
34    {
35       helpIncrement();
36
37       return *this;  // reference return to create an lvalue
38
39    } // end function operator++
40
41    // overloaded postincrement operator;
42    // integer parameter does not have a p
43    Date Date::operator++( int )
44    {
45       Date temp = *this;  // hold current state of object
46       helpIncrement();
47
48       // return unincremented, saved, temporary object
49       return temp;   // value return; not a reference return
50
51    } // end function operator++
```

Postincrement updates object and returns a copy of the original. Do not return a reference to temp, because it is a local variable that will be destroyed.

Also note that the integer parameter does not have a name.

Overloading

```
52
53    // add specified number of days to date
54    const Date &Date::operator+=( int additionalDays )
55    {
56       for ( int i = 0; i < additionalDays; i++ )
57          helpIncrement();
58
59       return *this;    // enables cascading
60
61    } // end function operator+=
62
63    // if the year is a leap year, return true;
64    // otherwise, return false
65    bool Date::leapYear( int testYear ) const
66    {
67       if ( testYear % 400 == 0 ||
68          ( testYear % 100 != 0 && testYear % 4 == 0 ) )
69          return true;   // a leap year
70       else
71          return false;  // not a leap year
72
73    } // end function leapYear
74
```

Overloading

```
75    // determine whether the day is the last day of the month
76    bool Date::endOfMonth( int testDay ) const
77    {
78       if ( month == 2 && leapYear( year ) )
79          return testDay == 29; // last day of Feb. in leap year
80       else
81          return testDay == days[ month ];
82
83    } // end function endOfMonth
84
85    // function to help increment the date
86    void Date::helpIncrement()
87    {
88       // day is not end of month
89       if ( !endOfMonth( day ) )
90          ++day;
91
92       else
93
94          // day is end of month and month < 12
95          if ( month < 12 ) {
96             ++month;
97             day = 1;
98          }
99
```

Overloading

```
100         // last day of year
101         else {
102            ++year;
103            month = 1;
104            day = 1;
105         }
106
107   } // end function helpIncrement
108
109   // overloaded output operator
110   ostream &operator<<( ostream &output, const Date &d )
111   {
112      static char *monthName[ 13 ] = { "", "January",
113         "February", "March", "April", "May", "June",
114         "July", "August", "September", "October",
115         "November", "December" };
116
117      output << monthName[ d.month ] << ' '
118             << d.day << ", " << d.year;
119
120      return output;   // enables cascading
121
122   } // end function operator<<
```

Overloading

```
1       // Fig. 8.12: fig08_12.cpp
2       // Date class test program.
3       #include <iostream>
4
5       using std::cout;
6       using std::endl;
7
8       #include "date1.h"  // Date class definition
9
10     int main()
11     {
12        Date d1;  // defaults to January 1, 1900
13        Date d2( 12, 27, 1992 );
14        Date d3( 0, 99, 8045 );  // invalid date
15
16        cout << "d1 is " << d1 << "\nd2 is " << d2
17             << "\nd3 is " << d3;
18
19        cout << "\n\nd2 += 7 is " << ( d2 += 7 );
20
21        d3.setDate( 2, 28, 1992 );
22        cout << "\n\n  d3 is " << d3;
23        cout << "\n++d3 is " << ++d3;
24
25        Date d4( 7, 13, 2002 );
```

Overloading

```
26
27       cout << "\n\nTesting the preincrement operator:\n"
28            << "  d4 is " << d4 << '\n';
29       cout << "++d4 is " << ++d4 << '\n';
30       cout << "  d4 is " << d4;
31
32       cout << "\n\nTesting the postincrement operator:\n"
33            << "  d4 is " << d4 << '\n';
34       cout << "d4++ is " << d4++ << '\n';
35       cout << "  d4 is " << d4 << endl;
36
37       return 0;
38
39    } // end main
```

Overloading

```
d1 is January 1, 1900
d2 is December 27, 1992
d3 is January 1, 1900

d2 += 7 is January 3, 1993

  d3 is February 28, 1992
++d3 is February 29, 1992

Testing the preincrement operator:
  d4 is July 13, 2002
++d4 is July 14, 2002
  d4 is July 14, 2002

Testing the postincrement operator:
  d4 is July 14, 2002
d4++ is July 14, 2002
  d4 is July 15, 2002
```

Esercitazione 8

Exercise 2

Implement a "Complex" class, which represents complex numbers. The data members are the real and imaginary part of the number.

- There must be a constructor composed by 2 double.
- Overload the operators +,-, *, =, ==,! =, <<, >>

N. B .: the functions that overload the operators << and >> must be declares as "friend" function

```
Execution example:
./usaComplessi.exe
Give me a complex number in the form: a + bi
3 + 5i
x: 0 + 0i
y: 4.3 + 8.2i
z: 3.3 + 1.1i
k: 3 + 5i
x = y + z:
7.6 + 9.3i = 4.3 + 8.2i + 3.3 + 1.1i
x = y - z:
1 + 7.1i = 4.3 + 8.2i - 3.3 + 1.1i
x = y * z:
23.21 + 31.79i = 4.3 + 8.2i * 3.3 + 1.1i
23.21 + 31.79i ! = 3 + 5i
3 + 5i == 3 + 5i
```

Esercitazione 8

Exercise 3

Implement a Vector class that represents vectors in 3 dimensions

(hint: use 3-component representation)

The class must have at least:

- a constructor with 3 double
- overloading of the operators <<, +,-
- the operation "scalar product"
- member functions that return the components and the form of the vector

Write a simple program that creates and uses objects of the Vector class

```
Execution example:
./useVettore.exe
 Vector v1 (1, 0, 0)
 Vector v2 (1, 1, 0)

 Vector v (2, 1, 0) sum of v1 vectors (1,
0, 0) and v2 (1, 1, 0)
 component x: 2
 component y: 1
 component z: 0
 form of v: 2.23607

 The scalar product of (1, 0, 0) and v2
(1, 1, 0): 1
```

`const` (Constant) Objects and `const` Member Functions

- Member initializer syntax
  - Initializing with member initializer syntax
    - Can be used for

      all data members
    - Must be used for

      `const` data members

      Data members that are references

`const` (Constant) Objects and `const` Member Functions

```
1     // Fig. 7.4: fig07_04.cpp
2     // Using a member initializer to initialize a
3     // constant of a built-in data type.
4     #include <iostream>
5
6     using std::cout;
7     using std::endl;
8
9     class Increment {
10
11    public:
12       Increment( int c = 0, int i = 1 );  // default constructor
13
14       void addIncrement()
15       {
16          count += increment;
17       } // end function addIncrement
18
19      void print() const;     // prints count and increment
20
21
```

const (Constant) Objects and const Member Functions

```
22    private:
23       int count;
24       const int increment;    // const data member
25
26    }; // end class Increment
27
28    // constructor
29    Increment::Increment( int c, int i )
30       : count( c ),     // initializer for non-const member
31         increment( i )  // required initializer for const member
32    {
33       // empty body
34
35    } // end Increment constructor
36
37    // print count and increment values
38    void Increment::print() const
39    {
40       cout << "count = " << count
41            << ", increment = " << increment << endl;
42
43    } // end function print
44
```

`const` (Constant) Objects and `const` Member Functions

```
22    private:
23       int count;
24       const int increment;    // const data member
25
26    }; // end class Increment
27
28    // constructor
29    Increment::Increment( in
30       : count( c ),      // initializer for non-const member
31         increment( i )   // required initializer for const member
32    {
33       // empty body
34
35    } // end Increment constructor
36
37    // print count and increment
38    void Increment::print() const
39    {
40       cout << "count = " << count
41            << ", increment = " << increment << endl;
42
43    } // end function print
44
```

Declare increment as **`const`** data member

Member initializer list separated from parameter list by colon

Member initializer syntax can be used for non-**`const`** data member **`count`**

Member initializer syntax must be used for **`const`** data member **`increment`**

Member initializer consists of data member name (**`increment`**) followed by parentheses containing initial value (**`i`**).

`const` (Constant) Objects and `const` Member Functions

```
45    int main()
46    {
47       Increment value( 10, 5 );
48
49       cout << "Before incrementing: ";
50       value.print();
51
52       for ( int j = 0; j < 3; j++ ) {
53          value.addIncrement();
54          cout << "After increment " << j + 1 << ": ";
55          value.print();
56       }
57
58       return 0;
59
60    } // end main
```

```
28    // constructor
29    Increment::Increment( int c, int i )
30       : count( c ),     // initializer for non-const member
31         increment( i )  // required initializer for const member
32    {
33       // empty body
```

```
Before incrementing: count = 10, increment = 5
After increment 1: count = 15, increment = 5
After increment 2: count = 20, increment = 5
After increment 3: count = 25, increment = 5
```

const (Constant) Objects and const Member Functions

```
1       // Fig. 7.5: fig07_05.cpp
2       // Attempting to initialize a constant of
3       // a built-in data type with an assignment.
4       #include <iostream>
5
6       using std::cout;
7       using std::endl;
8
9       class Increment {
10
11    public:
12       Increment( int c = 0, int i = 1 );  // default constructor
13
14       void addIncrement()
15       {
16          count += increment;
17
18       } // end function addIncrement
19
20       void print() const;     // prints count and increment
21
```

`const` (Constant) Objects and `const` Member Functions

```
22    private:
23       int count;
24       const int increment;     // const data member
25
26    }; // end class Increment
27
28    // constructor
29    Increment::Increment( int c, int i )
30    {              // Constant member 'increme
31       count = c;       // allowed because cou
32       increment = i;   // ERROR: Cannot modify a const object
33
34    } // end Increment constructor
35
36    // print count and increment values
37    void Increment::print() const
38    {
39       cout << "count = " << count
40            << ", increment = " << increment << endl;
41
42    } // end function print
43
```

Declare increment as **`const`** data member

Attempting to modify **`const`** data member **`increment`** results in error.

`const` (Constant) Objects and `const` Member Functions

```
44    int main()
45    {
46       Increment value( 10, 5 );
47
48       cout << "Before incrementing: ";
49       value.print();
50
51       for ( int j = 0; j < 3; j++ ) {
52          value.addIncrement();
53          cout << "After increment " << j + 1 << ": ";
54          value.print();
55       }
56
57       return 0;
58
59    } // end main
```

```
D:\cpphtp4_examples\ch07\Fig07_03\Fig07_03.cpp(30) : error C2758:
   'increment' : must be initialized in constructor base/member
   initializer list
        D:\cpphtp4_examples\ch07\Fig07_03\Fig07_03.cpp(24) :
           see declaration of 'increment'
D:\cpphtp4_examples\ch07\Fig07_03\Fig07_03.cpp(32) : error C2166:
   l-value specifies const object
```

Not using member initializer syntax to initialize **`const`** data member **`increment`** results in error.

Attempting to modify **`const`** data member **`increment`** results in error.

Composition: Objects as Members of Classes

- Composition
  - Class has objects of other classes as members
- Construction of objects
  - Member objects constructed in order declared
    - Not in order of constructor's member initializer list
    - Constructed before enclosing class objects (host objects)

`static` Class Members

- **`static`** class variable
  - "Class-wide" data
    - Property of class, not specific object of class
  - Efficient when single copy of data is enough
    - Only the **`static`** variable has to be updated
  - May seem like global variables, but have class scope
    - Only accessible to objects of same class
  - Initialized exactly once at file scope
  - Exist even if no objects of class exist
  - Can be **`public`**, **`private`** or **`protected`**

`static` Class Members

Accessing **`static`** class variables

Accessible through any object of class

- **`public static`** variables

Can also be accessed using binary scope resolution operator(**`::`**)

```
Employee::count
```

- **`private static`** variables

When no class member objects exist

Can only be accessed via **`public static`** member function

To call **`public static`** member function combine class name, binary scope resolution operator (**`::`**) and function name

```
Employee::getCount()
```

`static` Class Members

- **`static`** member functions
  - **C**annot access non-**`static`** data or functions

No **`this`** pointer for **`static`** functions

- **`static`** data members and **`static`** member functions exist independent of objects

```
1   // Fig. 7.17: employee2.h
2   // Employee class definition.
3   #ifndef EMPLOYEE2_H
4   #define EMPLOYEE2_H
5
6   class Employee {
7
8   public:
9      Employee( const char *, const char * );  // constructor
10     ~Employee();                             // destructor
11     const char *getFirstName() const;  // return first name
12     const char *getLastName() const;   // return last name
13
14     // static member function
15     static int getCount();  // return # objects instantiated
16
17  private:
18     char *firstName;
19     char *lastName;
20
21     // static data member
22     static int count;  // number of objects instantiated
23
24  }; // end class Employee
25
26  #endif
```

static member function can only access **static** data members and member functions

static data member is class-wide data

`static` Class Members

```
1   // Fig. 7.18: employee2.cpp
2   // Member-function definitions for class Employee.
3   #include <iostream>
4
5   using std::cout;
6   using std::endl;
7
8   #include <new>           // C++ standard new operator
9   #include <cstring>       // strcpy and strlen prototypes
10
11  #include "employee2.h"   // Employee clas
12
13  // define and initialize static data member
14  int Employee::count = 0;
15
16  // define static member function that re
17  // Employee objects instantiated
18  int Employee::getCount()
19  {
20     return count;
21
22  } // end static function getCount
```

Initialize **`static`** data member exactly once at file scope

`static` member function accesses **`static`** data member **`count`**

`static` Class Members

```
23
24    // constructor dynamically allocates space for
25    // first and last name and uses strcpy to copy
26    // first and last names into the object
27    Employee::Employee( const char *first, const char
28    {
29       firstName = new char[ strlen( first ) + 1 ];
30       strcpy( firstName, first );
31
32       lastName = new char[ st
33       strcpy( lastName, last
34
35       ++count;  // increment static count of employees
36
37       cout << "Employee constructor for " << firstName
38            << ' ' << lastName << " called." << endl;
39
40    } // end Employee constructor
41
42    // destructor deallocates dynamically allocated memory
43    Employee::~Employee()
44    {
45       cout << "~Employee() called for " << firstName
46            << ' ' << lastName << endl;
47
```

new operator dynamically allocates space

Use **static** data member to store total **count** of employees

`static` Class Members

```
48       delete [] firstName;  // recapture memory
49       delete [] lastName;   // recapture memory
50
51       --count;  // decrement static count of employees
52
53    } // end destructor ~Employee
54
55    // return first name of
56    const char *Employee::getFirstName() const
57    {
58       // const before return type prevents client from modifying
59       // private data; client should copy returned string before
60       // destructor deletes storage to prevent undefined pointer
61       return firstName;
62
63    } // end function getFirstName
64
65    // return last name of employee
66    const char *Employee::getLastName() const
67    {
68       // const before return type prevents client from modifying
69       // private data; client should copy returned string before
70       // destructor deletes storage to prevent undefined pointer
71       return lastName;
72
73    } // end function getLastName
```

Operator **`delete`** deallocates memory

Use **`static`** data member to store total **`count`** of employees

`static` Class Members

```
1      // Fig. 7.19: fig07_19.cpp
2      // Driver to test class Employee.
3      #include <iostream>
4
5      using std::cout;
6      using std::endl;
7
8      #include <new>           // C++ standard new operator
9
10    #include "employee2.h"  // Employee class definition
11
12    int main()
13    {
14       cout << "Number of employees before instantiation is "
15            << Employee::getCount() << endl;   // use class n
16
17       Employee *e1Ptr = new Employee( "Susan", "Baker" );
18       Employee *e2Ptr = new Employee( "Robert", "Jones" );
19
20       cout << "Number of employees after instantiation is "
21            << e1Ptr->getCount();
22
```

new operator dynamically allocates space

static member function can be invoked on any object of class

```
23       cout << "\n\nEmployee 1: "
24            << e1Ptr->getFirstName()
25            << " " << e1Ptr->getLastName()
26            << "\nEmployee 2: "
27            << e2Ptr->getFirstName()
28            << " " << e2Ptr->getLastName() << "
29
30       delete e1Ptr;  // recapture memory
31       e1Ptr = 0;     // disconnect pointer fr
32       delete e2Ptr;  // recapture memory
33       e2Ptr = 0;     // disconnect pointer fr
34
35       cout << "Number of employees after deletion is "
36            << Employee::getCount() << endl;
37
38       return 0;
39
40    } // end main
```

Operator **delete** deallocates memory

static member function invoked using binary scope resolution operator (no existing class objects)

```
Number of employees before instantiation is 0
Employee constructor for Susan Baker called.
Employee constructor for Robert Jones called.
Number of employees after instantiation is 2

Employee 1: Susan Baker
Employee 2: Robert Jones

~Employee() called for Susan Baker
~Employee() called for Robert Jones
Number of employees after deletion is 0
```

Standard Library Classes `string` and `vector`

- Classes built into C++
  - Available for anyone to use
    - **`string`**
  - Similar to our **`String`** class
    - **`vector`**
    - Dynamically resizable array
- Redo our **`String`** and **`Array`** examples
  - Use **`string`** and **`vector`**

Standard Library Classes `string` and `vector`

- Class **`string`**
  - Header **`<string>`**, namespace **`std`**
  - Can initialize **`string s1("hi");`**
  - Overloaded **`<<`**
    - **`cout << s1`**
  - Overloaded relational operators
    - **`== != >= > <= <`**
  - Assignment operator =
  - Concatenation (overloaded **`+=`**)

Standard Library Classes `string` and `vector`

- Class **`string`**
  - Substring function **`substr`**
    - **`s1.substr(0, 14);`**
  - Starts at location 0, gets 14 characters
    - **`S1.substr(15)`**
      - Substring beginning at location 15
  - Overloaded **`[]`**
    - Access one character
    - No range checking (if subscript invalid)
  - **`at`** function
    - **`s1.at(10)`**
    - Character at subscript 10
    - Has bounds checking
      - Will end program if invalid

Standard Library Classes

```
1     // Fig. 8.13: fig08_13.cpp
2     // Standard library string class test program.
3     #include <iostream>
4
5     using std::cout;
6     using std::endl;
7
8     #include <string>
9
10    using std::string;
11
12    int main()
13    {
14       string s1( "happy" );
15       string s2( " birthday" );
16       string s3;
17
18       // test overloaded equality and relational operators
19       cout << "s1 is \"" << s1 << "\"; s2 is \"" << s2
20            << "\"; s3 is \"" << s3 << '\"'
21            << "\n\nThe results of comparing s2 and s1:"
22            << "\ns2 == s1 yields "
23            << ( s2 == s1 ? "true" : "false" )
24            << "\ns2 != s1 yields "
25            << ( s2 != s1 ? "true" : "false" )
```

Standard Library Classes

```
26            << "\ns2 >  s1 yields "
27            << ( s2 > s1 ? "true" : "false" )
28            << "\ns2 <  s1 yields "
29            << ( s2 < s1 ? "true" : "false" )
30            << "\ns2 >= s1 yields "
31            << ( s2 >= s1 ? "true" : "false" )
32            << "\ns2 <= s1 yields "
33            << ( s2 <= s1 ? "true" : "false" );
34
35       // test string member function empty
36       cout << "\n\nTesting s3.empty():\n";
37
38       if ( s3.empty() ) {
39          cout << "s3 is empty; assigning s1 to s3;\n";
40          s3 = s1;  // assign s1 to s3
41          cout << "s3 is \"" << s3 << "\"";
42       }
43
44       // test overloaded string concatenation operator
45       cout << "\n\ns1 += s2 yields s1 = ";
46       s1 += s2;  // test overloaded concatenation
47       cout << s1;
48
```

Standard Library Classes

```
49       // test overloaded string concatenation operator
50       // with C-style string
51       cout << "\n\ns1 += \" to you\" yields\n";
52       s1 += " to you";
53       cout << "s1 = " << s1 << "\n\n";
54
55       // test string member function substr
56       cout << "The substring of s1 starting at location 0 for\n"
57            << "14 characters, s1.substr(0, 14), is:\n"
58            << s1.substr( 0, 14 ) << "\n\n";
59
60       // test substr "to-end-of-string" option
61       cout << "The substring of s1 starting at\n"
62            << "location 15, s1.substr(15), is:\n"
63            << s1.substr( 15 ) << '\n';
64
65       // test copy constructor
66       string *s4Ptr = new string( s1 );
67       cout << "\n*s4Ptr = " << *s4Ptr << "\n\n";
68
69       // test assignment (=) operator with self-assignment
70       cout << "assigning *s4Ptr to *s4Ptr\n";
71       *s4Ptr = *s4Ptr;
72       cout << "*s4Ptr = " << *s4Ptr << '\n';
73
```

Standard Library Classes

```
74        // test destructor
75        delete s4Ptr;
76
77        // test using subscript operator to create lvalue
78        s1[ 0 ] = 'H';
79        s1[ 6 ] = 'B';
80        cout << "\ns1 after s1[0] = 'H' and s1[6] = 'B' is: "
81             << s1 << "\n\n";
82
83        // test subscript out of range with string member function "at"
84        cout << "Attempt to assign 'd' to s1.at( 30 ) yields:" << endl;
85        s1.at( 30 ) = 'd';     // ERROR: subscript out of range
86
87        return 0;
88
89    } // end main
```

Standard Library Classes

```
s1 is "happy"; s2 is " birthday"; s3 is ""

The results of comparing s2 and s1:
s2 == s1 yields false
s2 != s1 yields true
s2 >  s1 yields false
s2 <  s1 yields true
s2 >= s1 yields false
s2 <= s1 yields true

Testing s3.empty():
s3 is empty; assigning s1 to s3;
s3 is "happy"

s1 += s2 yields s1 = happy birthday

s1 += " to you" yields
s1 = happy birthday to you

The substring of s1 starting at location 0 for
14 characters, s1.substr(0, 14), is:
happy birthday
```

Standard Library Classes

```
The substring of s1 starting at
location 15, s1.substr(15), is:
to you

*s4Ptr = happy birthday to you

assigning *s4Ptr to *s4Ptr
*s4Ptr = happy birthday to you

s1 after s1[0] = 'H' and s1[6] = 'B' is: Happy Birthday to you

Attempt to assign 'd' to s1.at( 30 ) yields:

abnormal program termination
```

Standard Library Classes `string` and `vector`

- Class **`vector`**
  - Header **`<vector>`**, namespace **`std`**
  - Store any type
    - **`vector< int > myArray(10)`**
  - Function **`size`** (**`myArray.size()`**)
  - Overloaded **`[]`**
    - Get specific element, **`myArray[3]`**
  - Overloaded **`!=`**, **`==`**, and **`=`**
    - Inequality, equality, assignment

Standard Library Classes Class vector

```
1      // Fig. 8.14: fig08_14.cpp
2      // Demonstrating standard library class vector.
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     #include <vector>
14
15     using std::vector;
16
17     void outputVector( const vector< int > & );
18     void inputVector( vector< int > & );
19
20     int main()
21     {
22        vector< int > integers1( 7 );   // 7-element vector< int >
23        vector< int > integers2( 10 );  // 10-element vector< int >
24
```

Standard Library Classes Class vector

```
25       // print integers1 size and contents
26       cout << "Size of vector integers1 is "
27            << integers1.size()
28            << "\nvector after initialization:\n";
29       outputVector( integers1 );
30
31       // print integers2 size and contents
32       cout << "\nSize of vector integers2 is "
33            << integers2.size()
34            << "\nvector after initialization:\n";
35       outputVector( integers2 );
36
37       // input and print integers1 and integers2
38       cout << "\nInput 17 integers:\n";
39       inputVector( integers1 );
40       inputVector( integers2 );
41
42       cout << "\nAfter input, the vectors contain:\n"
43            << "integers1:\n";
44       outputVector( integers1 );
45       cout << "integers2:\n";
46       outputVector( integers2 );
47
48       // use overloaded inequality (!=) operator
49       cout << "\nEvaluating: integers1 != integers2\n";
50
```

Standard Library Classes Class vector

```
51       if ( integers1 != integers2 )
52          cout << "integers1 and integers2 are not equal\n";
53
54       // create vector integers3 using integers1 as an
55       // initializer; print size and contents
56       vector< int > integers3( integers1 );  // copy constructor
57
58       cout << "\nSize of vector integers3 is "
59            << integers3.size()
60            << "\nvector after initialization:\n";
61       outputVector( integers3 );
62
63
64       // use overloaded assignment (=) operator
65       cout << "\nAssigning integers2 to integers1:\n";
66       integers1 = integers2;
67
68       cout << "integers1:\n";
69       outputVector( integers1 );
70       cout << "integers2:\n";
71       outputVector( integers1 );
72
```

Standard Library Classes Class vector

```
73       // use overloaded equality (==) operator
74       cout << "\nEvaluating: integers1 == integers2\n";
75
76       if ( integers1 == integers2 )
77          cout << "integers1 and integers2 are equal\n";
78
79       // use overloaded subscript operator to create rvalue
80       cout << "\nintegers1[5] is " << integers1[ 5 ];
81
82       // use overloaded subscript operator to create lvalue
83       cout << "\n\nAssigning 1000 to integers1[5]\n";
84       integers1[ 5 ] = 1000;
85       cout << "integers1:\n";
86       outputVector( integers1 );
87
88       // attempt to use out of range subscript
89       cout << "\nAttempt to assign 1000 to integers1.at( 15 )"
90            << endl;
91       integers1.at( 15 ) = 1000;  // ERROR: out of range
92
93       return 0;
94
95    } // end main
96
```

Standard Library Classes Class vector

```
97    // output vector contents
98    void outputVector( const vector< int > &array )
99    {
100     for ( int i = 0; i < array.size(); i++ ) {
101        cout << setw( 12 ) << array[ i ];
102
103        if ( ( i + 1 ) % 4 == 0 ) // 4 numbers per row of output
104           cout << endl;
105
106     } // end for
107
108     if ( i % 4 != 0 )
109        cout << endl;
110
111   } // end function outputVector
112
113   // input vector contents
114   void inputVector( vector< int > &array )
115   {
116      for ( int i = 0; i < array.size(); i++ )
117         cin >> array[ i ];
118
119   } // end function inputVector
```

Standard Library Classes Class vector

```
Size of vector integers1 is 7
vector after initialization:
           0           0           0           0
           0           0           0

Size of vector integers2 is 10
vector after initialization:
           0           0           0           0
           0           0           0           0
           0           0

Input 17 integers:
  1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

After input, the vectors contain:
integers1:
           1           2           3           4
           5           6           7
integers2:
           8           9          10          11
          12          13          14          15
          16          17

Evaluating: integers1 != integers2
integers1 and integers2 are not equal
```

Standard Library Classes Class vector

```
Size of vector integers3 is 7
vector after initialization:
          1           2           3           4
          5           6           7

Assigning integers2 to integers1:
integers1:
          8           9          10          11
         12          13          14          15
         16          17
integers2:
          8           9          10          11
         12          13          14          15
         16          17

Evaluating: integers1 == integers2
integers1 and integers2 are equal

integers1[5] is 13

Assigning 1000 to integers1[5]
integers1:
          8           9          10          11
         12        1000          14          15
         16          17

Attempt to assign 1000 to integers1.at( 15 )

abnormal program termination
```