10

Classes: A Deeper Look, Part 2

But what, to serve our private ends, Forbids the cheating of our friends?

— Charles Churchill

Instead of this absurd division into sexes they ought to class people as static and dynamic.

— Evelyn Waugh

Have no friends not equal to yourself.

— Confucius

OBJECTIVES

In this chapter you will learn:

- To specify `const` (constant) objects and `const` member functions.
- To create objects composed of other objects.
- To use `friend` functions and `friend` classes.
- To use the `this` pointer.
- To create and destroy objects dynamically with operators `new` and `delete`, respectively.
- To use `static` data members and member functions.
- The concept of a container class.
- The notion of iterator classes that walk through the elements of container classes.
- To use proxy classes to hide implementation details from a class's clients.

Outline

10.1 Introduction

- `const` objects and `const` member functions
  - Prevent modifications of objects
  - Enforce the principle of least privilege
- Composition
  - Classes having objects of other classes as members
- Friendship
  - Enables class designer to specify that certain non-member functions can access the class's non-`public` members

10.1 Introduction (Cont.)

- `this` pointer
- Dynamic memory management
  - `new` and `delete` operators
- `static` class members
- Proxy classes
  - Hide implementation details of a class from clients
- Pointer-base strings
  - Used in C legacy code from the last two decades

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

- Principle of least privilege
  - One of the most fundamental principles of good software engineering
  - Applies to objects, too
- `const` objects
  - Keyword `const`
  - Specifies that an object is not modifiable
  - Attempts to modify the object will result in compilation errors

Software Engineering Observation 10.1

Declaring an object as `const` helps enforce the principle of least privilege. Attempts to modify the object are caught at compile time rather than causing execution-time errors. Using `const` properly is crucial to proper class design, program design and coding.

Performance Tip 10.1

Declaring variables and objects `const` can improve performance—today's sophisticated optimizing compilers can perform certain optimizations on constants that cannot be performed on variables.

10.2 `const` (Constant) Objects and `const` Member Functions (Cont.)

- `const` member functions
  - Only `const` member function can be called for `const` objects
  - Member functions declared `const` are not allowed to modify the object
  - A function is specified as `const` both in its prototype and in its definition
  - `const` declarations are not allowed for constructors and destructors

Common Programming Error 10.1

Defining as `const` a member function that modifies a data member of an object is a compilation error.

Common Programming Error 10.2

Defining as `const` a member function that calls a non-`const` member function of the class on the same instance of the class is a compilation error.

Common Programming Error 10.3

Invoking a non-`const` member function on a `const` object is a compilation error.

Software Engineering Observation 10.2

A `const` member function can be overloaded with a non-`const` version. The compiler chooses which overloaded member function to use based on the object on which the function is invoked. If the object is `const`, the compiler uses the `const` version. If the object is not `const`, the compiler uses the non-`const` version.

Common Programming Error 10.4

Attempting to declare a constructor or destructor `const` is a compilation error.

```cpp
// Fig. 10.1: Time.h
// Definition of class Time.
// Member functions defined in Time.cpp.
#ifndef TIME_H
#define TIME_H

class Time
{
public:
   Time( int = 0, int = 0, int = 0 ); // default constructor

   // set functions
   void setTime( int, int, int ); // set time
   void setHour( int ); // set hour
   void setMinute( int ); // set minute
   void setSecond( int ); // set second

   // get functions (normally declared const)
   int getHour() const; // return hour
   int getMinute() const; // return minute
   int getSecond() const; // return second
```

`const` keyword to indicate that member function cannot modify the object

`Time.h`

```

   // print functions (normally declared const)
   void printUniversal() const; // print universal time
   void printStandard(); // print standard time (should be const)
private:
   int hour; // 0 - 23 (24-hour clock format)
   int minute; // 0 - 59
   int second; // 0 - 59
}; // end class Time

#endif
```

Outline

Time.cpp

(1 of 3)

```
// Fig. 10.2: Time.cpp
// Member-function definitions for class Time.
#include <iostream>
using std::cout;

#include <iomanip>
using std::setfill;
using std::setw;

#include "Time.h" // include definition of class Time

// constructor function to initialize private data;
// calls member function setTime to set variables;
// default values are 0 (see class definition)
Time::Time( int hour, int minute, int second )
{
   setTime( hour, minute, second );
} // end Time constructor

// set hour, minute and second values
void Time::setTime( int hour, int minute, int second )
{
   setHour( hour );
   setMinute( minute );
   setSecond( second );
} // end function setTime
```

```
// set hour value
void Time::setHour( int h )
{
   hour = ( h >= 0 && h < 24 ) ? h : 0; // validate hour
} // end function setHour

// set minute value
void Time::setMinute( int m )
{
   minute = ( m >= 0 && m < 60 ) ? m : 0; // validate minute
} // end function setMinute

// set second value
void Time::setSecond( int s )
{
   second = ( s >= 0 && s < 60 ) ? s : 0; // validate second
} // end function setSecond

// return hour value
int Time::getHour() const // get functions should be const
{
   return hour;
} // end function getHour
```

`const` keyword in function definition, as well as in function prototype

```
// return minute value
int Time::getMinute() const
{
   return minute;
} // end function getMinute

// return second value
int Time::getSecond() const
{
   return second;
} // end function getSecond

// print Time in universal-time format (HH:MM:SS)
void Time::printUniversal() const
{
   cout << setfill( '0' ) << setw( 2 ) << hour << ":"
      << setw( 2 ) << minute << ":" << setw( 2 ) << second;
} // end function printUniversal

// print Time in standard-time format (HH:MM:SS AM or PM)
void Time::printStandard() // note lack of const declaration
{
   cout << ( ( hour == 0 || hour == 12 ) ? 12 : hour % 12 )
      << ":" << setfill( '0' ) << setw( 2 ) << minute
      << ":" << setw( 2 ) << second << ( hour < 12 ? " AM" : " PM" );
} // end function printStandard
```

Time.cpp

(3 of 3)

Outline

```
// Fig. 10.3: fig10_03.cpp
// Attempting to access a const object with non-const member functions.
#include "Time.h" // include Time class definition

int main()
{
   Time wakeUp( 6, 45, 0 ); // non-constant object
   const Time noon( 12, 0, 0 ); // constant object

                              // OBJECT      MEMBER FUNCTION
   wakeUp.setHour( 18 );  // non-const   non-const

   noon.setHour( 12 );    // const       non-const

   wakeUp.getHour();      // non-const   const

   noon.getMinute();      // const       const
   noon.printUniversal(); // const       const

   noon.printStandard();  // const       non-const
   return 0;
} // end main
```

fig10_03.cpp

(1 of 2)

Cannot invoke non-**const** member functions on a **const** object

Outline

fig10_03.cpp

(2 of 2)

Borland C++ command-line compiler error messages:

```
Warning W8037 fig10_03.cpp 13: Non-const function Time::setHour(int)
   called for const object in function main()
Warning W8037 fig10_03.cpp 20: Non-const function Time::printStandard()
   called for const object in function main()
```

Microsoft Visual C++.NET compiler error messages:

```
C:\cpphtp5_examples\ch10\Fig10_01_03\fig10_03.cpp(13) : error C2662:
   'Time::setHour' : cannot convert 'this' pointer from 'const Time' to
   'Time &'
        Conversion loses qualifiers
C:\cpphtp5_examples\ch10\Fig10_01_03\fig10_03.cpp(20) : error C2662:
   'Time::printStandard' : cannot convert 'this' pointer from 'const Time' to
   'Time &'
        Conversion loses qualifiers
```

GNU C++ compiler error messages:

```
fig10_03.cpp:13: error: passing `const Time' as `this' argument of
   `void Time::setHour(int)' discards qualifiers
fig10_03.cpp:20: error: passing `const Time' as `this' argument of
   `void Time::printStandard()' discards qualifiers
```

10.2 const (Constant) Objects and const Member Functions (Cont.)

- **Member initializer**
  - **Required for initializing**
    - `const` **data members**
    - **Data members that are references**
  - **Can be used for any data member**
- **Member initializer list**
  - **Appears between a constructor's parameter list and the left brace that begins the constructor's body**
  - **Separated from the parameter list with a colon (`:`)**
  - **Each member initializer consists of the data member name followed by parentheses containing the member's initial value**
  - **Multiple member initializers are separated by commas**
  - **Executes before the body of the constructor executes**

```cpp
// Fig. 10.4: Increment.h
// Definition of class Increment.
#ifndef INCREMENT_H
#define INCREMENT_H

class Increment
{
public:
   Increment( int c = 0, int i = 1 ); // default constructor

   // function addIncrement definition
   void addIncrement()
   {
      count += increment;
   } // end function addIncrement

   void print() const; // prints count and increment
private:
   int count;
   const int increment; // const data member
}; // end class Increment

#endif
```

const data member that must be initialized using a member initializer

Increment.h

Outline

```
// Fig. 10.5: Increment.cpp
// Member-function definitions for class Increment demonstrate using a
// member initializer to initialize a constant of a built-in data type.
#include <iostream>
using std::cout;
using std::endl;

#include "Increment.h" // include definition of class Increment

// constructor
Increment::Increment( int c, int i )
   : count( c ), // initializer for non-const member
     increment( i ) // required initializer for const member
{
   // empty body
} // end constructor Increment

// print count and increment values
void Increment::print() const
{
   cout << "count = " << count << ", increment = " << increment << endl;
} // end function print
```

Colon (**:**) marks the start of a member initializer list

Member initializer for non-**const** member **count**

Required member initializer for **const** member **increment**

Increment.cpp

(1 of 1)

Outline

```cpp
// Fig. 10.6: fig10_06.cpp
// Program to test class Increment.
#include <iostream>
using std::cout;

#include "Increment.h" // include definition of class Increment

int main()
{
   Increment value( 10, 5 );

   cout << "Before incrementing: ";
   value.print();

   for ( int j = 1; j <= 3; j++ )
   {
      value.addIncrement();
      cout << "After increment " << j << ": ";
      value.print();
   } // end for

   return 0;
} // end main
```

```
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
```

fig10_06.cpp

(1 of 1)

Software Engineering Observation 10.3

A `const` object cannot be modified by assignment, so it must be initialized. When a data member of a class is declared `const`, a member initializer must be used to provide the constructor with the initial value of the data member for an object of the class. The same is true for references.

Common Programming Error 10.5

Not providing a member initializer for a `const` data member is a compilation error.

Software Engineering Observation 10.4

Constant data members (`const` objects and `const` variables) and data members declared as references must be initialized with member initializer syntax; assignments for these types of data in the constructor body are not allowed.

Error-Prevention Tip 10.1

Declare as `const` all of a class's member functions that do not modify the object in which they operate. Occasionally this may seem inappropriate, because you will have no intention of creating `const` objects of that class or accessing objects of that class through `const` references or pointers to `const`. Declaring such member functions `const` does offer a benefit, though. If the member function is inadvertently written to modify the object, the compiler will issue an error message.

```cpp
// Fig. 10.7: Increment.h
// Definition of class Increment.
#ifndef INCREMENT_H
#define INCREMENT_H

class Increment
{
public:
   Increment( int c = 0, int i = 1 ); // default constructor

   // function addIncrement definition
   void addIncrement()
   {
      count += increment;
   } // end function addIncrement

   void print() const; // prints count and increment
private:
   int count;
   const int increment; // const data member
}; // end class Increment

#endif
```

Member function declared **`const`** to prevent errors in situations where an **`Increment`** object is treated as a **`const`** object

```
// Fig. 10.8: Increment.cpp
// Attempting to initialize a constant of
// a built-in data type with an assignment.
#include <iostream>
using std::cout;
using std::endl;

#include "Increment.h" // include definition of class Increment

// constructor; constant member 'increment' is not initialized
Increment::Increment( int c, int i )
{
   count = c; // allowed because count is not constant
   increment = i; // ERROR: Cannot modify a const object
} // end constructor Increment

// print count and increment values
void Increment::print() const
{
   cout << "count = " << count << ", increment = " << increment << endl;
} // end function print
```

It is an error to modify a **`const`** data member; data member **`increment`** must be initialized with a member initializer

`Increment.cpp`

(1 of 1)

Outline

fig10_09.cpp

(1 of 2)

```
// Fig. 10.9: fig10_09.cpp
// Program to test class Increment.
#include <iostream>
using std::cout;

#include "Increment.h" // include definition of class Increment

int main()
{
   Increment value( 10, 5 );

   cout << "Before incrementing: ";
   value.print();

   for ( int j = 1; j <= 3; j++ )
   {
      value.addIncrement();
      cout << "After increment " << j << ": ";
      value.print();
   } // end for

   return 0;
} // end main
```

Borland C++ command-line compiler error message:

```
Error E2024 Increment.cpp 14: Cannot modify a const object in function
   Increment::Increment(int,int)
```

Microsoft Visual C++.NET compiler error messages:

```
C:\cpphtp5_examples\ch10\Fig10_07_09\Increment.cpp(12) : error C2758:
   'Increment::increment' : must be initialized in constructor
   base/member initializer list
         C:\cpphtp5_examples\ch10\Fig10_07_09\Increment.h(20) :
            see declaration of 'Increment::increment'
C:\cpphtp5_examples\ch10\Fig10_07_09\Increment.cpp(14) : error C2166:
   l-value specifies const object
```

GNU C++ compiler error messages:

```
Increment.cpp:12: error: uninitialized member 'Increment::increment' with
   'const' type 'const int'
Increment.cpp:14: error: assignment of read-only data-member
   `Increment::increment'
```

10.3 Composition: Objects as Members of Classes

- **Composition**
  - **Sometimes referred to as a *has-a* relationship**
  - **A class can have objects of other classes as members**
  - **Example**
    - `AlarmClock` **object with a** `Time` **object as a member**

10.3 Composition: Objects as Members of Classes (Cont.)

- **Initializing member objects**
  - **Member initializers pass arguments from the object's constructor to member-object constructors**
  - **Member objects are constructed in the order in which they are declared in the class definition**
    - **Not in the order they are listed in the constructor's member initializer list**
    - **Before the enclosing class object (host object) is constructed**
  - **If a member initializer is not provided**
    - **The member object's default constructor will be called implicitly**

Software Engineering Observation 10.5

A common form of software reusability is composition, in which a class has objects of other classes as members.

Outline

```
// Fig. 10.10: Date.h
// Date class definition; Member functions defined in Date.cpp
#ifndef DATE_H
#define DATE_H

class Date
{
public:
   Date( int = 1, int = 1, int = 1900 ); // default constructor
   void print() const; // print date in month/day/year format
   ~Date(); // provided to confirm destruction order
private:
   int month; // 1-12 (January-December)
   int day; // 1-31 based on month
   int year; // any year

   // utility function to check if day is proper for month and year
   int checkDay( int ) const;
}; // end class Date

#endif
```

Date.h

(1 of 1)

Outline

Date.cpp

(1 of 3)

```
// Fig. 10.11: Date.cpp
// Member-function definitions for class Date.
#include <iostream>
using std::cout;
using std::endl;

#include "Date.h" // include Date class definition

// constructor confirms proper value for month; calls
// utility function checkDay to confirm proper value for day
Date::Date( int mn, int dy, int yr )
{
   if ( mn > 0 && mn <= 12 ) // validate the month
      month = mn;
   else
   {
      month = 1; // invalid month set to 1
      cout << "Invalid month (" << mn << ") set to 1.\n";
   } // end else

   year = yr; // could validate yr
   day = checkDay( dy ); // validate the day

   // output Date object to show when its constructor is called
   cout << "Date object constructor for date ";
   print();
   cout << endl;
} // end Date constructor
```

Outline

Date.cpp

(2 of 3)

```

// print Date object in form month/day/year
void Date::print() const
{
   cout << month << '/' << day << '/' << year;
} // end function print

// output Date object to show when its destructor is called
Date::~Date()
{
   cout << "Date object destructor for date ";
   print();
   cout << endl;
} // end ~Date destructor
```

Outline

Date.cpp

(3 of 3)

```
// utility function to confirm proper day value based on
// month and year; handles leap years, too
int Date::checkDay( int testDay ) const
{
   static const int daysPerMonth[ 13 ] =
      { 0, 31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31 };

   // determine whether testDay is valid for specified month
   if ( testDay > 0 && testDay <= daysPerMonth[ month ] )
      return testDay;

   // February 29 check for leap year
   if ( month == 2 && testDay == 29 && ( year % 400 == 0 ||
      ( year % 4 == 0 && year % 100 != 0 ) ) )
      return testDay;

   cout << "Invalid day (" << testDay << ") set to 1.\n";
   return 1; // leave object in consistent state if bad value
} // end function checkDay
```

Outline

Employee.h

(1 of 1)

```
// Fig. 10.12: Employee.h
// Employee class definition.
// Member functions defined in Employee.cpp.
#ifndef EMPLOYEE_H
#define EMPLOYEE_H

#include "Date.h" // include Date class definition

class Employee
{
public:
   Employee( const char * const, const char * const,
      const Date &, const Date & );
   void print() const;
   ~Employee(); // provided to confirm de
private:
   char firstName[ 25 ];
   char lastName[ 25 ];
   const Date birthDate; // composition: member object
   const Date hireDate; // composition: member object
}; // end class Employee

#endif
```

Parameters to be passed via member initializers to the constructor for class `Date`

`const` objects of class `Date` as members

Outline

Employee.cpp

(1 of 2)

```
// Fig. 10.13: Employee.cpp
// Member-function definitions for class Employee.
#include <iostream>
using std::cout;
using std::endl;

#include <cstring> // strlen and strncpy prototypes
using std::strlen;
using std::strncpy;

#include "Employee.h" // Employee class definition
#include "Date.h" // Date class definition

// constructor uses member initializer list to pass initializer
// values to constructors of member objects birthDate and hireDate
// [Note: This invokes the so-called "default copy constructor" which the
// C++ compiler provides implicitly.]
Employee::Employee( const char * const first, const char * const last,
   const Date &dateOfBirth, const Date &dateOfHire )
   : birthDate( dateOfBirth ), // initialize birthDate
     hireDate( dateOfHire ) // initialize hireDate
{
   // copy first into firstName and be
   int length = strlen( first );
   length = ( length < 25 ? length : 24 );
   strncpy( firstName, first, length );
   firstName[ length ] = '\0';
```

Member initializers that pass arguments to **Date**'s implicit default copy constructor

```
   // copy last into lastName and be sure that it fits
   length = strlen( last );
   length = ( length < 25 ? length : 24 );
   strncpy( lastName, last, length );
   lastName[ length ] = '\0';

   // output Employee object to show when constructor is called
   cout << "Employee object constructor: "
      << firstName << ' ' << lastName << endl;
} // end Employee constructor

// print Employee object
void Employee::print() const
{
   cout << lastName << ", " << firstName << "  Hired: ";
   hireDate.print();
   cout << "  Birthday: ";
   birthDate.print();
   cout << endl;
} // end function print

// output Employee object to show when its destructor is called
Employee::~Employee()
{
   cout << "Employee object destructor: "
      << lastName << ", " << firstName << endl;
} // end ~Employee destructor
```

Outline

Employee.cpp

(2 of 2)

```cpp
// Fig. 10.14: fig10_14.cpp
// Demonstrating composition--an object with member objects.
#include <iostream>
using std::cout;
using std::endl;

#include "Employee.h" // Employee class definition

int main()
{
   Date birth( 7, 24, 1949 );
   Date hire( 3, 12, 1988 );
   Employee manager( "Bob", "Blue", birth, hire );

   cout << endl;
   manager.print();

   cout << "\nTest Date constructor with invalid values:\n";
   Date lastDayOff( 14, 35, 1994 ); // invalid month and day
   cout << endl;
   return 0;
} // end main
```

Passing objects to a host object constructor

Outline

```
Date object constructor for date 7/24/1949
Date object constructor for date 3/12/1988
Employee object constructor: Bob Blue

Blue, Bob  Hired: 3/12/1988  Birthday: 7/24/1949

Test Date constructor with invalid values:
Invalid month (14) set to 1.
Invalid day (35) set to 1.
Date object constructor for date 1/1/1994

Date object destructor for date 1/1/1994
Employee object destructor: Blue, Bob
Date object destructor for date 3/12/1988
Date object destructor for date 7/24/1949
Date object destructor for date 3/12/1988
Date object destructor for date 7/24/1949
```

fig10_14.cpp

(2 of 2)

Common Programming Error 10.6

A compilation error occurs if a member object is not initialized with a member initializer and the member object’s class does not provide a default constructor (i.e., the member object’s class defines one or more constructors, but none is a default constructor).

Performance Tip 10.2

Initialize member objects explicitly through member initializers. This eliminates the overhead of “doubly initializing” member objects—once when the member object’s default constructor is called and again when *set* functions are called in the constructor body (or later) to initialize the member object.

Software Engineering Observation 10.6

If a class member is an object of another class, making that member object `public` does not violate the encapsulation and hiding of that member object's `private` members. However, it does violate the encapsulation and hiding of the containing class's implementation, so member objects of class types should still be `private`, like all other data members.

10.4 `friend` Functions and `friend` Classes

- **`friend` function of a class**
  - **Defined outside that class's scope**
    - **Not a member function of that class**
  - **Yet has the right to access the non-`public` (and `public`) members of that class**
  - **Standalone functions or entire classes may be declared to be friends of a class**
  - **Can enhance performance**
  - **Often appropriate when a member function cannot be used for certain operations**

10.4 friend Functions and friend Classes (Cont.)

- To declare a function as a `friend` of a class:
  - Provide the function prototype in the class definition preceded by keyword `friend`
- To declare a class as a friend of a class:
  - Place a declaration of the form

    ```
    friend class ClassTwo;
    ```

    in the definition of class `ClassOne`
    - All member functions of class `ClassTwo` are `friends` of class `ClassOne`

10.4 `friend` Functions and `friend` Classes (Cont.)

- **Friendship is granted, not taken**
  - **For class `B` to be a friend of class `A`, class `A` must explicitly declare that class `B` is its friend**
- **Friendship relation is neither symmetric nor transitive**
  - **If class `A` is a friend of class `B`, and class `B` is a friend of class `C`, you cannot infer that class `B` is a friend of class `A`, that class `C` is a friend of class `B`, or that class `A` is a friend of class `C`**
- **It is possible to specify overloaded functions as `friends` of a class**
  - **Each overloaded function intended to be a `friend` must be explicitly declared as a `friend` of the class**

Software Engineering Observation 10.7

Even though the prototypes for `friend` functions appear in the class definition, friends are not member functions.

Software Engineering Observation 10.8

Member access notions of `private`, `protected` and `public` are not relevant to `friend` declarations, so `friend` declarations can be placed anywhere in a class definition.

Good Programming Practice 10.1

Place all friendship declarations first inside the class definition’s body and do not precede them with any access specifier.

Software Engineering Observation 10.9

Some people in the OOP community feel that "friendship" corrupts information hiding and weakens the value of the object-oriented design approach. In this text, we identify several examples of the responsible use of friendship.

```cpp
// Fig. 10.15: fig10_15.cpp
// Friends can access private members of a class.
#include <iostream>
using std::cout;
using std::endl;

// Count class definition
class Count
{
   friend void setX( Count &, int ); // friend declaration
public:
   // constructor
   Count()
      : x( 0 ) // initialize x to 0
   {
      // empty body
   } // end constructor Count

   // output x
   void print() const
   {
      cout << x << endl;
   } // end function print
private:
   int x; // data member
}; // end class Count
```

friend function declaration (can appear anywhere in the class)

Outline

fig10_15.cpp

Outline

fig10_15.cpp

```
// function setX can modify private data of Count
// because setX is declared as a friend of Count (line 10)
void setX( Count &c, int val )
{
   c.x = val; // allowed because setX is a friend of Count
} // end function setX

int main()
{
   Count counter; // create Count object

   cout << "counter.x after instantiation: ";
   counter.print();

   setX( counter, 8 ); // set x using a friend function
   cout << "counter.x after call to setX friend function: ";
   counter.print();
   return 0;
} // end main
```

friend function can modify **Count**'s **private** data

Calling a **friend** function; note that we pass the **Count** object to the function

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

Outline

```
// Fig. 10.16: fig10_16.cpp
// Non-friend/non-member functions cannot access private data of a class.
#include <iostream>
using std::cout;
using std::endl;

// Count class definition (note that there is no friendship declaration)
class Count
{
public:
   // constructor
   Count()
      : x( 0 ) // initialize x to 0
   {
      // empty body
   } // end constructor Count

   // output x
   void print() const
   {
      cout << x << endl;
   } // end function print
private:
   int x; // data member
}; // end class Count
```

fig10_16.cpp

(1 of 3)

```

// function cannotSetX tries to modify private data of Count,
// but cannot because the function is not a friend of Count
void cannotSetX( Count &c, int val )
{
   c.x = val; // ERROR: cannot access private member in Count
} // end function cannotSetX

int main()
{
   Count counter; // create Count object

   cannotSetX( counter, 3 ); // cannotSetX is not a friend
   return 0;
} // end main
```

Non-**`friend`** function cannot access the class's **`private`** data

`fig10_16.cpp`

Outline

fig10_16.cpp

(3 of 3)

Borland C++ command-line compiler error message:

```
Error E2247 Fig10_16/fig10_16.cpp 31: 'Count::x' is not accessible in
   function cannotSetX(Count &,int)
```

Microsoft Visual C++.NET compiler error messages:

```
C:\cpphtp5_examples\ch10\Fig10_16\fig10_16.cpp(31) : error C2248: 'Count::x'
   : cannot access private member declared in class 'Count'
        C:\cpphtp5_examples\ch10\Fig10_16\fig10_16.cpp(24) : see declaration
           of 'Count::x'
        C:\cpphtp5_examples\ch10\Fig10_16\fig10_16.cpp(9) : see declaration
           of 'Count'
```

GNU C++ compiler error messages:

```
fig10_16.cpp:24: error: 'int Count::x' is private
fig10_16.cpp:31: error: within this context
```

10.5 Using the `this` Pointer

- **Member functions know which object's data members to manipulate**
  - **Every object has access to its own address through a pointer called `this` (a C++ keyword)**
  - **An object's `this` pointer is not part of the object itself**
  - **The `this` pointer is passed (by the compiler) as an implicit argument to each of the object's non-`static` member functions**
- **Objects use the `this` pointer implicitly or explicitly**
  - **Implicitly when accessing members directly**
  - **Explicitly when using keyword `this`**
  - **Type of the `this` pointer depends on the type of the object and whether the executing member function is declared `const`**

Outline

fig10_17.cpp

(1 of 2)

```
// Fig. 10.17: fig10_17.cpp
// Using the this pointer to refer to object members.
#include <iostream>
using std::cout;
using std::endl;

class Test
{
public:
   Test( int = 0 ); // default constructor
   void print() const;
private:
   int x;
}; // end class Test

// constructor
Test::Test( int value )
   : x( value ) // initialize x to value
{
   // empty body
} // end constructor Test
```

Outline

fig10_17.cpp


```cpp

// print x using implicit and explicit this pointers;
// the parentheses around *this are required
void Test::print() const
{
   // implicitly use the this pointer to access the member x
   cout << "        x = " << x;

   // explicitly use the this pointer and the arrow operator
   // to access the member x
   cout << "\n  this->x = " << this->x;

   // explicitly use the dereferenced this pointer and
   // the dot operator to access the member x
   cout << "\n(*this).x = " << ( *this ).x << endl;
} // end function print

int main()
{
   Test testObject( 12 ); // instantiate and initialize testObject

   testObject.print();
   return 0;
} // end main
```

Implicitly using the **this** pointer to access member **x**

Explicitly using the **this** pointer to access member **x**

Using the dereferenced **this** pointer and the dot operator

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

Common Programming Error 10.7

Attempting to use the member selection operator (.) with a pointer to an object is a compilation error—the dot member selection operator may be used only with an *lvalue* such as an object's name, a reference to an object or a dereferenced pointer to an object.

10.5 Using the `this` Pointer (Cont.)

- **Cascaded member-function calls**
  - **Multiple functions are invoked in the same statement**
  - **Enabled by member functions returning the dereferenced `this` pointer**
  - **Example**
    - `t.setMinute( 30 ).setSecond( 22 );`
      - **Calls** `t.setMinute( 30 );`
      - **Then calls** `t.setSecond( 22 );`

```
// Fig. 10.18: Time.h
// Cascading member function calls.

// Time class definition.
// Member functions defined in Time.cpp.
#ifndef TIME_H
#define TIME_H

class Time
{
public:
   Time( int = 0, int = 0, int = 0 ); // default constructor

   // set functions (the Time & return types enable cascading)
   Time &setTime( int, int, int ); // set hour, minute, second
   Time &setHour( int ); // set hour
   Time &setMinute( int ); // set minute
   Time &setSecond( int ); // set second
```

set functions return **`Time &`** to enable cascading

Outline

`Time.h`

(1 of 2)

Outline

Time.h

(2 of 2)

```
   // get functions (normally declared const)
   int getHour() const; // return hour
   int getMinute() const; // return minute
   int getSecond() const; // return second

   // print functions (normally declared const)
   void printUniversal() const; // print universal time
   void printStandard() const; // print standard time
private:
   int hour; // 0 - 23 (24-hour clock format)
   int minute; // 0 - 59
   int second; // 0 - 59
}; // end class Time

#endif
```

```
// Fig. 10.19: Time.cpp
// Member-function definitions for Time class.
#include <iostream>
using std::cout;

#include <iomanip>
using std::setfill;
using std::setw;

#include "Time.h" // Time class definition

// constructor function to initialize private data;
// calls member function setTime to set variables;
// default values are 0 (see class definition)
Time::Time( int hr, int min, int sec )
{
   setTime( hr, min, sec );
} // end Time constructor

// set values of hour, minute, and second
Time &Time::setTime( int h, int m, int s ) // note Time & return
{
   setHour( h );
   setMinute( m );
   setSecond( s );
   return *this; // enables cascading
} // end function setTime
```

Returning dereferenced **this** pointer enables cascading

Time.cpp

(1 of 3)

Outline

```
// set hour value
Time &Time::setHour( int h ) // note Time & return
{
   hour = ( h >= 0 && h < 24 ) ? h : 0; // validate hour
   return *this; // enables cascading
} // end function setHour

// set minute value
Time &Time::setMinute( int m ) // note Time & return
{
   minute = ( m >= 0 && m < 60 ) ? m : 0; // validate minute
   return *this; // enables cascading
} // end function setMinute

// set second value
Time &Time::setSecond( int s ) // note Time & return
{
   second = ( s >= 0 && s < 60 ) ? s : 0; // validate second
   return *this; // enables cascading
} // end function setSecond

// get hour value
int Time::getHour() const
{
   return hour;
} // end function getHour
```

Time.cpp

(2 of 3)

Outline

Time.cpp

(3 of 3)

```

// get minute value
int Time::getMinute() const
{
   return minute;
} // end function getMinute

// get second value
int Time::getSecond() const
{
   return second;
} // end function getSecond

// print Time in universal-time format (HH:MM:SS)
void Time::printUniversal() const
{
   cout << setfill( '0' ) << setw( 2 ) << hour << ":"
      << setw( 2 ) << minute << ":" << setw( 2 ) << second;
} // end function printUniversal

// print Time in standard-time format (HH:MM:SS AM or PM)
void Time::printStandard() const
{
   cout << ( ( hour == 0 || hour == 12 ) ? 12 : hour % 12 )
      << ":" << setfill( '0' ) << setw( 2 ) << minute
      << ":" << setw( 2 ) << second << ( hour < 12 ? " AM" : " PM" );
} // end function printStandard
```

```
// Fig. 10.20: fig10_20.cpp
// Cascading member function calls with the this pointer.
#include <iostream>
using std::cout;
using std::endl;

#include "Time.h" // Time class definition

int main()
{
   Time t; // create Time object

   // cascaded function calls
   t.setHour( 18 ).setMinute( 30 ).setSecond( 22 );

   // output time in universal and standard formats
   cout << "Universal time: ";
   t.printUniversal();

   cout << "\nStandard time: ";
   t.printStandard();

   cout << "\n\nNew standard time: ";

   // cascaded function calls
   t.setTime( 20, 20, 20 ).printStandard();
   cout << endl;
   return 0;
} // end main
```

Cascaded function calls using the reference returned by one function call to invoke the next

Note that these calls must appear in the order shown, because **`printStandard`** does not return a reference to **`t`**

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

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

10.6 Dynamic Memory Management with Operators `new` and `delete`

- **Dynamic memory management**
  - **Enables programmers to allocate and deallocate memory for any built-in or user-defined type**
  - **Performed by operators `new` and `delete`**
  - **For example, dynamically allocating memory for an array instead of using a fixed-size array**

10.6 Dynamic Memory Management with Operators `new` and `delete` (Cont.)

- Operator `new`
  - Allocates (i.e., reserves) storage of the proper size for an object at execution time
  - Calls a constructor to initialize the object
  - Returns a pointer of the type specified to the right of `new`
  - Can be used to dynamically allocate any fundamental type (such as `int` or `double`) or any class type
- Free store
  - Sometimes called the heap
  - Region of memory assigned to each program for storing objects created at execution time

10.6 Dynamic Memory Management with Operators new and `delete` (Cont.)

- **Operator `delete`**
  - **Destroys a dynamically allocated object**
  - **Calls the destructor for the object**
  - **Deallocates (i.e., releases) memory from the free store**
  - **The memory can then be reused by the system to allocate other objects**

10.6 Dynamic Memory Management with Operators new and delete (Cont.)

- **Initializing an object allocated by `new`**
  - **Initializer for a newly created fundamental-type variable**
    - **Example**
      - `double *ptr = new double( 3.14159 );`
  - **Specify a comma-separated list of arguments to the constructor of an object**
    - **Example**
      - `Time *timePtr = new Time( 12, 45, 0 );`

Common Programming Error 10.8

Not releasing dynamically allocated memory when it is no longer needed can cause the system to run out of memory prematurely. This is sometimes called a "memory leak."

10.6 Dynamic Memory Management with Operators `new` and `delete` (Cont.)

- `new` operator can be used to allocate arrays dynamically
  - Dynamically allocate a 10-element integer array:

    ```
    int *gradesArray = new int[ 10 ];
    ```

  - Size of a dynamically allocated array
    - Specified using any integral expression that can be evaluated at execution time

10.6 Dynamic Memory Management with Operators new and `delete` (Cont.)

- **Delete a dynamically allocated array:**

  ```
  delete [] gradesArray;
  ```

  - **This deallocates the array to which `gradesArray` points**
  - **If the pointer points to an array of objects**
    - **First calls the destructor for every object in the array**
    - **Then deallocates the memory**
  - **If the statement did not include the square brackets (`[]`) and `gradesArray` pointed to an array of objects**
    - **Only the first object in the array would have a destructor call**

Common Programming Error 10.9

Using `delete` instead of `delete []` for arrays of objects can lead to runtime logic errors. To ensure that every object in the array receives a destructor call, always delete memory allocated as an array with operator `delete []`. Similarly, always delete memory allocated as an individual element with operator `delete`.

10.7 `static` Class Members

- `static` data member
  - Only one copy of a variable shared by all objects of a class
    - “Class-wide” information
    - A property of the class shared by all instances, not a property of a specific object of the class
  - Declaration begins with keyword `static`

10.7 `static` Class Members (Cont.)

- `static` data member (Cont.)
  - Example
    - Video game with `Martian`s and other space creatures
      - Each `Martian` needs to know the `martianCount`
      - `martianCount` should be `static` class-wide data
      - Every `Martian` can access `martianCount` as if it were a data member of that `Martian`
      - Only one copy of `martianCount` exists
  - May seem like global variables but have class scope
  - Can be declared `public`, `private` or `protected`

10.7 `static` Class Members (Cont.)

- `static` data member (Cont.)
  - Fundamental-type `static` data members
    - Initialized by default to `0`
    - If you want a different initial value, a static data member can be initialized once (and only once)
  - A `const static` data member of `int` or `enum` type
    - Can be initialized in its declaration in the class definition
  - All other `static` data members
    - Must be defined at file scope (i.e., outside the body of the class definition)
    - Can be initialized only in those definitions
  - `static` data members of class types (i.e., `static` member objects) that have default constructors
    - Need not be initialized because their default constructors will be called

10.7 `static` Class Members (Cont.)

- `static` data member (Cont.)
  - Exists even when no objects of the class exist
    - To access a `public static` class member when no objects of the class exist
      - Prefix the class name and the binary scope resolution operator (`::`) to the name of the data member
      - Example
        - `Martian::martianCount`
  - Also accessible through any object of that class
    - Use the object’s name, the dot operator and the name of the member
      - Example
        - `myMartian.martianCount`

10.7 `static` Class Members (Cont.)

- `static` member function
  - Is a service of the *class*, not of a specific object of the class
- `static` applied to an item at file scope
  - That item becomes known only in that file
  - The `static` members of the class need to be available from any client code that accesses the file
    - So we cannot declare them `static` in the `.cpp` file—we declare them `static` only in the `.h` file.

Performance Tip 10.3

Use `static` data members to save storage when a single copy of the data for all objects of a class will suffice.

Software Engineering Observation 10.10

A class's `static` data members and `static` member functions exist and can be used even if no objects of that class have been instantiated.

Common Programming Error 10.10

It is a compilation error to include keyword `static` in the definition of a `static` data members at file scope.

```
// Fig. 10.21: Employee.h
// Employee class definition.
#ifndef EMPLOYEE_H
#define EMPLOYEE_H

class Employee
{
public:
   Employee( const char * const, const char * const ); // constructor
   ~Employee(); // destructor
   const char *getFirstName() const; // return first name
   const char *getLastName() const; // return last name

   // static member function
   static int getCount(); // return number of objects instantiated
private:
   char *firstName;
   char *lastName;

   // static data
   static int count; // number of objects instantiated
}; // end class Employee

#endif
```

Function prototype for **static** member function

static data member keeps track of number of **Employee** objects that currently exist

Outline

```
// Fig. 10.22: Employee.cpp
// Member-function definitions for class Employee.
#include <iostream>
using std::cout;
using std::endl;

#include <cstring> // strlen and strcpy prototypes
using std::strlen;
using std::strcpy;

#include "Employee.h" // Employee class definition

// define and initialize static data member at file scope
int Employee::count = 0;

// define static member functio
// Employee objects instantiate
int Employee::getCount()
{
   return count;
} // end static function getCount
```

static data member is defined and initialized at file scope in the **.cpp** file

static member function can access only **static** data, because the function might be called when no objects exist

Employee.cpp

(1 of 3)

Outline

Employee.cpp

(2 of 3)

```
// constructor dynamically allocates space for first and last name and
// uses strcpy to copy first and last names into the object
Employee::Employee( const char * const first, const char * const last )
{
   firstName = new char[ strlen( first ) + 1 ];
   strcpy( firstName, first );

   lastName = new char[ strlen( last ) + 1 ];
   strcpy( lastName, last );

   count++; // increment static count of employees

   cout << "Employee constructor for " << firstName
      << ' ' << lastName << " called." << endl;
} // end Employee constructor

// destructor deallocates dynamically allocated memory
Employee::~Employee()
{
   cout << "~Employee() called for " << firstName
      << ' ' << lastName << endl;

   delete [] firstName; // release memory
   delete [] lastName; // release memory

   count--; // decrement static count of employees
} // end ~Employee destructor
```

Dynamically allocating **char** arrays

Non-**static** member function (i.e., constructor) can modify the class's **static** data members

Deallocating memory reserved for arrays

```
// return first name of employee
const char *Employee::getFirstName() const
{
   // const before return type prevents client from modifying
   // private data; client should copy returned string before
   // destructor deletes storage to prevent undefined pointer
   return firstName;
} // end function getFirstName

// return last name of employee
const char *Employee::getLastName() const
{
   // const before return type prevents client from modifying
   // private data; client should copy returned string before
   // destructor deletes storage to prevent undefined pointer
   return lastName;
} // end function getLastName
```

Outline

fig10_23.cpp

(1 of 2)

```
// Fig. 10.23: fig10_23.cpp
// Driver to test class Employee.
#include <iostream>
using std::cout;
using std::endl;

#include "Employee.h" // Employee class definition

int main()
{
   // use class name and binary scope resolution operator to
   // access static number function getCount
   cout << "Number of employees before instantiation of any objects is "
      << Employee::getCount() << endl; // use class name

   // use new to dynamically create two new Employe
   // operator new also calls the object's construc
   Employee *e1Ptr = new Employee( "Susan", "Baker" );
   Employee *e2Ptr = new Employee( "Robert", "Jones" );

   // call getCount on first Employee object
   cout << "Number of employees after objects
      << e1Ptr->getCount();

   cout << "\n\nEmployee 1: "
      << e1Ptr->getFirstName() << " " << e
      << "\nEmployee 2: "
      << e2Ptr->getFirstName() << " " << e2Ptr->getLastName() << "\n\n";
```

Calling **static** member function using class name and binary scope resolution operator

Dynamically creating **Employee**s with **new**

Calling a **static** member function through a pointer to an object of the class

Outline

```
   delete e1Ptr; // deallocate memory
   e1Ptr = 0; // disconnect pointer from free-store space
   delete e2Ptr; // deallocate memory
   e2Ptr = 0; // disconnect pointer fro

   // no objects exist, so ca
   // using the class name and the binary scope resolution operator
   cout << "Number of employees after objects are deleted is "
      << Employee::getCount() << endl;
   return 0;
} // end main
```

Releasing memory to which a pointer points

Disconnecting a pointer from any space in memory

fig10_23.cpp

(2 of 2)

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

Employee 1: Susan Baker
Employee 2: Robert Jones

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

10.7 `static` Class Members (Cont.)

- **Declare a member function `static`**
  - **If it does not access non-`static` data members or non-`static` member functions of the class**
  - **A `static` member function does not have a `this` pointer**
  - **`static` data members and `static` member functions exist independently of any objects of a class**
  - **When a `static` member function is called, there might not be any objects of its class in memory**

Software Engineering Observation 10.11

Some organizations specify in their software engineering standards that all calls to `static` member functions be made using the class name and not an object handle.

Common Programming Error 10.11

Using the `this` pointer in a `static` member function is a compilation error.

Common Programming Error 10.12

Declaring a `static` member function `const` is a compilation error. The `const` qualifier indicates that a function cannot modify the contents of the object in which it operates, but `static` member functions exist and operate independently of any objects of the class.

Error-Prevention Tip 10.2

After deleting dynamically allocated memory, set the pointer that referred to that memory to `0`. This disconnects the pointer from the previously allocated space on the free store. This space in memory could still contain information, despite having been deleted. By setting the pointer to `0`, the program loses any access to that free-store space, which, in fact, could have already been reallocated for a different purpose. If you didn't set the pointer to `0`, your code could inadvertently access this new information, causing extremely subtle, nonrepeatable logic errors.

10.8 Data Abstraction and Information Hiding

- **Information Hiding**
  - **A class normally hides implementation details from clients**
- **Data abstraction**
  - **Client cares about *what* functionality a class offers, not about *how* that functionality is implemented**
    - **For example, a client of a stack class need not be concerned with the stack's implementation (e.g., a linked list)**
  - **Programmers should not write code that depends on a class's implementation details**

10.8 Data Abstraction and Information Hiding (Cont.)

- **Importance of data**
  - **Elevated in C++ and object-oriented community**
    - **Primary activities of object-oriented programming in C++**
      - **Creation of types (i.e., classes)**
      - **Expression of the interactions among objects of those types**
  - **Abstract data types (ADTs)**
    - **Improve the program development process**

10.8 Data Abstraction and Information Hiding (Cont.)

- **Abstract data types (ADTs)**
  - **Essentially ways of representing real-world notions to some satisfactory level of precision within a computer system**
  - **Types like `int`, `double`, `char` and others are all ADTs**
    - **e.g., `int` is an abstract representation of an integer**
  - **Capture two notions:**
    - **Data representation**
    - **Operations that can be performed on the data**
  - **C++ classes implement ADTs and their services**

10.8.1 Example: Array Abstract Data Type

- **Many array operations not built into C++**
  - **e.g., subscript range checking**
- **Programmers can develop an array ADT as a class that is preferable to “raw” arrays**
  - **Can provide many helpful new capabilities**
- **C++ Standard Library class template `vector`**

Software Engineering Observation 10.12

The programmer is able to create new types through the class mechanism. These new types can be designed to be used as conveniently as the built-in types. Thus, C++ is an extensible language. Although the language is easy to extend with these new types, the base language itself cannot be changed.

10.8.2 Example: String Abstract Data Type

- No string data type among C++'s built-in data types
  - C++ is an intentionally sparse language
    - Provides programmers with only the raw capabilities needed to build a broad range of systems
    - Designed to minimize performance burdens
    - Designed to include mechanisms for creating and implementing string abstract data types through classes
  - C++ Standard Library class `string`

10.8.3 Example: Queue Abstract Data Type

- **Queue ADT**
  - **Items returned in first-in, first-out (FIFO) order**
    - **First item inserted in the queue is the first item removed from the queue**
  - **Hides an internal data representation that somehow keeps track of the items currently waiting in line**
  - **Good example of an abstract data type**
    - **Clients invoke *enqueue* operation to put things in the queue one at a time**
    - **Clients invoke *dequeue* operation to get those things back one at a time on demand**
  - **C++ Standard Library `queue` class**

10.9 Container Classes and Iterators

- **Container classes (also called collection classes)**
  - **Classes designed to hold collections of objects**
  - **Commonly provide services such as insertion, deletion, searching, sorting, and testing an item to determine whether it is a member of the collection**
  - **Examples**
    - **Arrays**
    - **Stacks**
    - **Queues**
    - **Trees**
    - **Linked lists**

10.9 Container Classes and Iterators (Cont.)

- **Iterator objects—or more simply iterators**
  - **Commonly associated with container classes**
  - **An object that “walks through” a collection, returning the next item (or performing some action on the next item)**
  - **A container class can have several iterators operating on it at once**
  - **Each iterator maintains its own “position” information**

10.10 Proxy Classes

- **Header files contain some portion of a class's implementation and hints about others**
  - **For example, a class's `private` members are listed in the class definition in a header file**
  - **Potentially exposes proprietary information to clients of the class**

10.10 Proxy Classes (Cont.)

- **Proxy class**
  - **Hides even the `private` data of a class from clients**
  - **Knows only the `public` interface of your class**
  - **Enables the clients to use your class's services without giving the client access to your class's implementation details**

Outline

```
// Fig. 10.24: Implementation.h
// Header file for class Implementation

class Implementation
{
public:
   // constructor
   Implementation( int v )
      : value( v ) // initialize value with v
   {
      // empty body
   } // end constructor Implementation

   // set value to v
   void setValue( int v )
   {
      value = v; // should validate v
   } // end function setValue

   // return value
   int getValue() const
   {
      return value;
   } // end function getValue
private:
   int value; // data that we would like to hide from the client
}; // end class Implementation
```

Class definition for the class that contains the proprietary implementation we would like to hide

The data we would like to hide from the client

Implementation.h

(1 of 1)

```cpp
// Fig. 10.25: Interface.h
// Header file for class Interface
// Client sees this source code, but the source code does not reveal
// the data layout of class Implementation.

class Implementation; // forward class declaration required by line 17

class Interface
{
public:
   Interface( int ); // constructor
   void setValue( int ); // same public interface as
   int getValue() const; // class Implementation has
   ~Interface(); // destructor
private:
   // requires previous forward declaration (line 6)
   Implementation *ptr;
}; // end class Interface
```

Declares **`Implementation`** as a data type without including the class's complete header file

`public` interface between client and hidden class

Using a pointer allows us to hide implementation details of class **`Implementation`**

Outline

`Interface.h`

(1 of 1)

```
// Fig. 10.26: Interface.cpp
// Implementation of class Interface--client receives this file only
// as precompiled object code, keeping the implementation hidden.
#include "Interface.h" // Interface class definition
#include "Implementation.h" // Implementation class definition

// constructor
Interface::Interface( int v )
   : ptr ( new Implementation( v ) )
{                                      // a new Implementation object
   // empty body
} // end Interface constructor

// call Implementation's setValue function
void Interface::setValue( int v )
{
   ptr->setValue( v );
} // end function setValue

// call Implementation's getValue function
int Interface::getValue() const
{
   return ptr->getValue();
} // end function getValue

// destructor
Interface::~Interface()
{
   delete ptr;
} // end ~Interface destructor
```

Only location where **`Implementation.h`** is included with **`#include`**

Setting the value of the hidden data via a pointer

Getting the value of the hidden data via a pointer

`Interface.cpp`

```
// Fig. 10.27: fig10_27.cpp
// Hiding a class's private data with a proxy class.
#include <iostream>
using std::cout;
using std::endl;

#include "Interface.h" // Interface class definition

int main()
{
   Interface i( 5 ); // creat

   cout << "Interface contains: " << i.getValue()
      << " before setValue" << endl;

   i.setValue( 10 );

   cout << "Interface contains: " << i.getValue()
      << " after setValue" << endl;
   return 0;
} // end main
```

Only the header file for **`Interface`** is included in the client code—no mention of the existence of a separate class called **`Implementation`**

```
Interface contains: 5 before setValue
Interface contains: 10 after setValue
```

Software Engineering Observation 10.13

A proxy class insulates client code from implementation changes.