Classes: A Deeper Look
Deeper into C++ Classes

- `const` objects and `const` member functions
- Composition
- Friendship
- `this` pointer
- Dynamic memory management
  - `new` and `delete` operators
- `static` class members and member functions
- Abstract data types
21.2 const (Constant) Objects and const

Member Functions

- Principle of least privilege
  - “allowing access to data only when it is absolutely needed.”
  - Is 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.

Example
- **Const Time noon (12, 0, 0):**
**`const` (Constant) Objects and `const` Member Functions**

- **`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.
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.
const Example

// Fig. 21.1: 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
};
#endif // TIME_H

Systems Programming: Deeper into C++ Classes
const Example

22
23 // print functions (normally declared const)
24 void printUniversal() const; // print universal time
25 void printStandard(); // print standard time (should be const)
26 private:
27 int hour; // 0 - 23 (24-hour clock format)
28 int minute; // 0 - 59
29 int second; // 0 - 59
30 }; // end class Time
31
32 #endif
// Fig. 21.2: 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
const Example

```cpp
27 // set hour value
28 void Time::setHour( int h )
29 {
30     hour = ( h >= 0 && h < 24 ) ? h : 0; // validate hour
31 } // end function setHour
32
33 // set minute value
34 void Time::setMinute( int m )
35 {
36     minute = ( m >= 0 && m < 60 ) ? m : 0; // validate minute
37 } // end function setMinute
38
39 // set second value
40 void Time::setSecond( int s )
41 {
42     second = ( s >= 0 && s < 60 ) ? s : 0; // validate second
43 } // end function setSecond
44
45 // return hour value
46 int Time::getHour() const // get functions should be const
47 {
48     return hour;
49 } // end function getHour
```

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

51
52 // return minute value
53 int Time::getMinute() const
54 {
55     return minute;
56 } // end function getMinute
57
58 // return second value
59 int Time::getSecond() const
60 {
61     return second;
62 } // end function getSecond
63
64 // print Time in universal-time format (HH:MM:SS)
65 void Time::printUniversal() const
66 {
67     cout << setfill( '0' ) << setw( 2 ) << hour << " : "
68         << setw( 2 ) << minute << " : " << setw( 2 ) << second;
69 } // end function printUniversal
70
71 // print Time in standard-time format (HH:MM:SS AM or PM)
72 void Time::printStandard() // note lack of const declaration
73 {
74     cout << ( ( hour == 0 || hour == 12 ) ? 12 : hour % 12 )
75         << " : " << setfill( '0' ) << setw( 2 ) << minute
76         << " : " << setw( 2 ) << second << ( hour < 12 ? " AM" : " PM" );
77 } // end function printStandard
// Fig. 21.3: fig21_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

    noon.setMinute();    // const       const
    noon.printUniversal(); // const       const
    noon.printStandard(); // const       non-const

    return 0;
} // end main

Cannot invoke non-const member functions on a const object
Borland C++ command-line compiler error messages:

```
Warning W8037 fig21_03.cpp 13: Non-const function Time::setHour(int)
   called for const object in function main()
Warning W8037 fig21_03.cpp 20: Non-const function Time::printStandard()
   called for const object in function main()
```

Microsoft Visual C++.NET compiler error messages:

```
C:\examples\ch21\Fig21_01_03\fig21_03.cpp(13) : error C2662:
   'Time::setHour' : cannot convert 'this' pointer from 'const Time' to
   'Time &'
   Conversion loses qualifiers
C:\examples\ch21\Fig21_01_03\fig21_03.cpp(20) : error C2662:
   'Time::printStandard' : cannot convert 'this' pointer from 'const Time' to
   'Time &'
   Conversion loses qualifiers
```

GNU C++ compiler error messages:

```
Fig21_03.cpp:13: error: passing `const Time' as `this' argument of
   `void Time::setHour(int)' discards qualifiers
Fig21_03.cpp:20: error: passing `const Time' as `this' argument of
   `void Time::printStandard()' discards qualifiers
```
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.
// Fig. 21.4: 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

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// Fig. 21.5: 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>
#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
{

// 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

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```cpp
// Fig. 21.6: fig21_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
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.
• Not providing a member initializer for a \texttt{const} data member is a compilation error.
Software Engineering Observation 21.4

- 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.
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.
Composition: Objects as Members of Classes

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

// Fig. 21.10: 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
// Fig. 21.11: 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
        { // invalid month set to 1
            month = 1; // invalid month set to 1
            cout << "Invalid month (" << mn << ") set to 1.";
        } // 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
// 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
// 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
Composition Example

```cpp
// Fig. 21.12: 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 destruction

  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
Composition Example

```cpp
// Fig. 21.13: 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 sure that it fits
    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
```
Composition Example

28
29  // copy last into lastName and be sure that it fits
30  length = strlen( last );
31  length = ( length < 25 ? length : 24 );
32  strncpy( lastName, last, length );
33  lastName[ length ] = '\0';
34
35  // output Employee object to show when constructor is called
36  cout << "Employee object constructor: "
37     << firstName << ' ' << lastName << endl;
38 } // end Employee constructor
39
40  // print Employee object
41  void Employee::print() const
42  {
43    cout << lastName << ", " << firstName << " Hired: ";
44    hireDate.print();
45    cout << " Birthday: ";
46    birthDate.print();
47    cout << endl;
48 } // end function print
49
50  // output Employee object to show when its destructor is called
51  Employee::~Employee()
52  {
53    cout << "Employee object destructor: "
54       << lastName << ", " << firstName << endl;
55 } // end ~Employee destructor

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// Fig. 21.14: fig21_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
Composition Example

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


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
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).
21.4 **friend** Functions and **friend** Classes

- **friend** function of a class
  - Defined outside that class’s scope.
  - Not a member function of that class.
  - 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.
**friend Functions and friend Classes**

- 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 another 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`. 
friend Functions and friend Classes

- 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.
friend Functions and friend Classes

- 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.
friend Function Example

// Fig. 21.15: fig21_15.cpp
// Friends can access private members of a class.
#include <iostream>
using namespace std;

// Count class definition
class Count
{
friend void setX( Count & x ); // 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)
# friend Function Example

```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: ";
    cout << counter.print();
    setX( counter, 8 ); // set x using a friend function
    cout << "counter.x after call to setX friend function: ";
    cout << 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
```
// 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
friend Function Example

// 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
}

int main()
{
    Count counter; // create Count object
    cannotSetX( counter, 3 ); // cannotSetX is not a friend
    return 0;
}

Non-friend function cannot access the class’s private data
friend Function Example

**Borland C++ command-line compiler error message:**

```
Error E2247 Fig21_16/fig21_16.cpp 31: 'Count::x' is not accessible in function cannotSetX(Count & int)
```

**Microsoft Visual C++.NET compiler error messages:**

```
C:\examples\ch21\Fig21_16\fig21_16.cpp(31) : error C2248: 'Count::x'
    : cannot access private member declared in class 'Count'
C:\examples\ch21\Fig21_16\fig21_16.cpp(24) : see declaration of 'Count::x'
C:\examples\ch21\Fig21_16\fig21_16.cpp(9) : see declaration of 'Count'
```

**GNU C++ compiler error messages:**

```
Fig21_16.cpp:24: error: 'int Count::x' is private
Fig21_16.cpp:31: error: within this context
```
21.5 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.
21.5 Using the **this** Pointer

- Objects use the **this** pointer implicitly or explicitly.
  - **this** is used implicitly when accessing members directly.
  - It is used explicitly when using keyword **this**.
  - The type of the **this** pointer depends on the type of the object and whether the executing member function is declared **const**.
```cpp
// Fig. 21.17: fig21_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
```

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// 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 << "this->x = " << this->x;

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

int main()
{
    Test testObject( 12 ); // instantiate and initialize testObject
    testObject.print();
    return 0;
}

x = 12
this->x = 12
(*this).x = 12
• 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.
Using the `this` Pointer

- **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);`
Cascading Function Calls
using the **this** Pointer

```cpp
// Fig. 21.18: Time.h
// Cascading member function calls.

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

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
```
Cascading Function Calls using the this Pointer

```cpp
// 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
```
Cascading Function Calls
using the **this** Pointer

```cpp
// Fig. 21.19: 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
Cascading Function Calls using the this Pointer

```cpp
// 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
```
Cascading Function Calls using the this Pointer

```cpp
55 // get minute value
56 int Time::getMinute() const
57 {
58     return minute;
59 } // end function getMinute
60
62 // get second value
63 int Time::getSecond() const
64 {
65     return second;
66 } // end function getSecond
67
68 // print Time in universal-time format (HH:MM:SS)
69 void Time::printUniversal() const
70 {
71     cout << setfill( '0' ) << setw( 2 ) << hour << ":" << 
72     setw( 2 ) << minute << ":" << setw( 2 ) << second;
73 } // end function printUniversal
74
75 // print Time in standard-time format (HH:MM:SS AM or PM)
76 void Time::printStandard() const
77 {
78     cout << ( ( hour == 0 || hour == 12 ) ? 12 : hour % 12 )
79     << ":" << setfill( '0' ) << setw( 2 ) << minute
80     << ":" << setw( 2 ) << second << ( hour < 12 ? " AM" : " PM" );
81 } // end function printStandard
```
// Fig. 21.20: fig21_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
Cascading Function Calls using the this Pointer

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

New standard time: 8:20:20 PM
21.6 Dynamic Memory Management: 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.
Operators **new** and **delete**

- **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.
- **The Free store** (referred to as the heap)
  - Region of memory assigned to each program for storing objects created at execution time.

**Example:**

```cpp
Time *timePtr

timePtr = new Time;
```
Operators **new and delete**

- **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.

Example:

```
delete timePtr;
```
Operators *new* and *delete*

- Initializing an object allocated by *new*
  - Initializer for a newly created fundamental-type variable.

Example

```cpp
double *ptr = new double( 3.14159 );
```

- Specify a comma-separated list of arguments to the constructor of an object.

Example

```cpp
Time *timePtr = new Time( 12, 45, 0 );
```
Operators **new** and **delete**

- **new** operator can be used to allocate arrays dynamically.
  - Dynamically allocate a 10-element integer array:
    ```cpp
    int *gradesArray = new int[10];
    ```
  - Size of a dynamically allocated array
    - Specified using any integral expression that can be evaluated at execution time.
    ```cpp
    Stores * storeptr = new Stores[first_floor];
    ```
Operators `new` and `delete`

- Delete a dynamically allocated array:
  ```
  delete [] gradesArray;
  ```
- This deallocates the array to which `gradesArray` points.
- If the pointer points to an array of objects,
  - It first calls the destructor for every object in the array.
  - Then it 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.
21.7 **static** Class Members

- **static** data member
  - Only one copy of a variable shared by all objects of a class.
    - The member is “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**
**static Class Members**

- **Example**
  - Video game with Martians 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 static has class scope.
  - Can be declared public, private or protected.
**static Class Members**

- **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).

- **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.
static Class Members

- 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
**static Class Members**

- **static** member function
  - *Is a service of the class*, not of a specific object of the class.
- **static** is 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.
static class member Example

```cpp
// Fig. 21.21: 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**
static class member Example

// Fig. 21.22: Employee.cpp
// Member-function definitions for class Employee.
#include <iostream>
using namespace std;
#include <cstring> // strlen and strcpy prototypes
using namespace std;
#include "Employee.h" // Employee class definition

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

// define static member function that returns number of
// Employee objects instantiated (declared static in Employee.h)
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

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// 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

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50
51 // return first name of employee
52 const char *Employee::getFirstName() const
53 {
54    // const before return type prevents client from modifying
55    // private data; client should copy returned string before
56    // destructor deletes storage to prevent undefined pointer
57    return firstName;
58 } // end function getFirstName
59
60 // return last name of employee
61 const char *Employee::getLastName() const
62 {
63    // const before return type prevents client from modifying
64    // private data; client should copy returned string before
65    // destructor deletes storage to prevent undefined pointer
66    return lastName;
67 } // end function getLastName
static class member Example

```
// Fig. 21.23: fig21_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 Employees
    // operator new also calls the object's constructor
    Employee *e1Ptr = new Employee( "Susan", "Baker" );
    Employee *e2Ptr = new Employee( "Robert", "Jones" );
    // call getCount on first Employee object
    cout << "Number of employees after objects are instantiated is "
         << e1Ptr->getCount();
    cout << "\n\nEmployee 1: "
         << e1Ptr->getFirstName() << " " << e1Ptr->getLastName()
         << "\nEmployee 2: "
         << e2Ptr->getFirstName() << " " << e2Ptr->getLastName() << "\n";
```
static class member Example

```cpp
static class member Example

29  delete e1Ptr; // deallocate memory
30
31  e1Ptr = 0; // disconnect pointer from free-store space
32  delete e2Ptr; // deallocate memory
33
34  // no objects exist, so call static member function getCount again
35  // using the class name and the binary scope resolution operator
36  cout << "Number of employees after objects are deleted is "
37  << Employee::getCount() << endl;
38
39  return 0;
40  } // end main
```

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

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static Class Members

- 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.
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.
- Captures two notions:
  - Data representation
  - Operations that can be performed on the data.
- **C++ classes implement ADTs and their services.**
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*. 
Summary

- **const** objects and **const** member functions
- Member Composition Example
- **friend** function Example
- **this** pointer Example
- Dynamic memory management
  - **new** and **delete** operators
- **static** class members
- Abstract Data Types