IS 0020
Program Design and Software Tools

Introduction to C++ Programming

Lecture 3: Classes

May 24, 2004

Classes

Structure Definitions

- Structures
  - Aggregate data types built using elements of other types

```
struct Time {
     int hour;
     int minute;
     int second;
};
```

Structure tag

Structure members

- Structure member naming
  - In same **`struct`**: must have unique names
  - In different **`struct`**s: can share name
- **`struct`** definition must end with semicolon

Structure Definitions

- Self-referential structure
  - Structure member cannot be instance of enclosing **`struct`**
  - Structure member can be pointer to instance of enclosing **`struct`** (self-referential structure)
    - Used for linked lists, queues, stacks and trees
- **`struct`** definition
  - Creates new data type used to declare variables
  - Structure variables declared like variables of other types
  - Examples:
    - **`Time timeObject;`**
    - **`Time timeArray[ 10 ];`**
    - **`Time *timePtr;`**
    - **`Time &timeRef = timeObject;`**

Accessing Structure Members

- Member access operators
  - Dot operator (**.**) for structure and class members
  - Arrow operator (**->**) for structure and class members via pointer to object
  - Print member **hour** of **timeObject**:

```
cout << timeObject.hour;
```

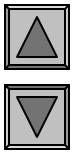
OR

```
timePtr = &timeObject;
cout << timePtr->hour;
```

  - **timePtr->hour** same as **(*timePtr).hour**
    - Parentheses required
      - * lower precedence than .

Implementing a User-Defined Type Time with a `struct`

- Default: structures passed by value
  - Pass structure by reference
    - Avoid overhead of copying structure
- C-style structures
  - No “interface”
    - If implementation changes, all programs using that **`struct`** must change accordingly
  - Cannot print as unit
    - Must print/format member by member
  - Cannot compare in entirety
    - Must compare member by member



Outline

fig06_01.cpp
(1 of 3)

```
1  // Fig. 6.1: fig06_01.cpp
2  // Create a structure, set its members, and print it.
3  #include <iostream>
4
5  using std::cout;
6  using std::endl;
7
8  #include <iomanip>
9
10 using std::setfill;
11 using std::setw;
12
13 // structure definition
14 struct Time {
15    int hour;     // 0-23 (24-hour clock format)
16    int minute;   // 0-59
17    int second;   // 0-59
18
19 }; // end struct Time
20
21 void printUniversal( const Time & );  // prototype
22 void printStandard( const Time & );   // prototype
23
```

Define structure type **`Time`** with three integer members.

Pass references to constant **`Time`** objects to eliminate copying overhead.

Implementing a `Time` Abstract Data Type with a `class`

- Classes
  - Model objects
    - Attributes (data members)
    - Behaviors (member functions)
  - Defined using keyword **`class`**
  - Member functions
    - Methods
    - Invoked in response to messages
- Member access specifiers
  - **`public:`**
    - Accessible wherever object of class in scope
  - **`private:`**
    - Accessible only to member functions of class
  - **`protected:`**

Implementing a `Time` Abstract Data Type with a `class`

- Constructor function
  - Special member function
    - Initializes data members
    - Same name as class
  - Called when object instantiated
  - Several constructors
    - Function overloading
  - No return type

Implementing a `Time` Abstract Data Type with a `class`

- Objects of class
  - After class definition
    - Class name new type specifier
      - C++ extensible language
    - Object, array, pointer and reference declarations
  - Example:

Class name becomes new type specifier.

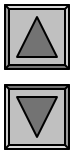
```
Time sunset;                    // object of type Time
Time arrayOfTimes[ 5 ];         // array of Time objects
Time *pointerToTime;            // pointer to a Time object
Time &dinnerTime = sunset;      // reference to a Time object
```

Implementing a `Time` Abstract Data Type with a `class`

- Member functions defined outside class
  - Binary scope resolution operator (`::`)

```
ReturnType ClassName::MemberFunctionName(
  ){
  …
}
```

- Member functions defined inside class
  - Do not need scope resolution operator, class name
  - Compiler attempts **`inline`**
    - Outside class, inline explicitly with keyword **`inline`**

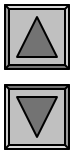


Outline

fig06_03.cpp
(1 of 5)

```
1  // Fig. 6.3: fig06_03.cpp
2  // Time class.
3  #include <iostream>
4
5  using std::cout;
6  using std::endl;
7
8  #include <iomanip>
9
10 using std::setfill;
11 using std::setw;
12
13 // Time abstract data type (ADT) definition
14 class Time {
15
16 public:
17    Time();                          // constructor
18    void setTime( int, int, int ); // set hour, minute, second
19    void printUniversal();         // print universal-time format
20    void printStandard();          // print standard-time format
21
```

Define class **`Time`**.



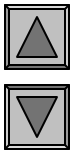
Outline

fig06_03.cpp
(2 of 5)

```
22 private:
23    int hour;     // 0 - 23 (24-hour clock format)
24    int minute;   // 0 - 59
25    int second;   // 0 - 59
26
27 }; // end class Time
28
29 // Time constructor initializes each data m
30 // ensures all Time objects start in a cons
31 Time::Time()
32 {
33    hour = minute = second = 0;
34
35 } // end Time constructor
36
37 // set new Time value using universal time, perform validity
38 // checks on the data values and set invalid values to zero
39 void Time::setTime( int h, int m, int s )
40 {
41    hour = ( h >= 0 && h < 24 ) ? h : 0;
42    minute = ( m >= 0 && m < 60 ) ? m : 0;
43    second = ( s >= 0 && s < 60 ) ? s : 0;
44
45 } // end function setTime
46
```

Constructor initializes **`private`** data members to **`0`**.

`public` member function checks parameter values for validity before setting **`private`** data members.



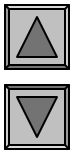
Outline

fig06_03.cpp
(3 of 5)

```
47 // print Time in universal format
48 void Time::printUniversal()
49 {
50    cout << setfill( '0' ) << setw( 2 ) << hour << ":"
51         << setw( 2 ) << minute << ":"
52         << setw( 2 ) << second;
53
54 } // end function printUniversal
55
56 // print Time in standard format
57 void Time::printStandard()
58 {
59    cout << ( ( hour == 0 || hour == 12 ) ? 12 : hour % 12 )
60         << ":" << setfill( '0' ) << setw( 2 ) << minute
61         << ":" << setw( 2 ) << second
62         << ( hour < 12 ? " AM" : " PM" );
63
64 } // end function print
65
66 int main()
67 {
68    Time t;  // instantiate object t of class Time
69
```

No arguments (implicitly "know" purpose is to print data members); member function calls more concise.

Declare variable **t** to be object of class **Time**.



Outline

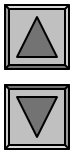
```
70    // output Time object t's initial values
71    cout << "The initial universal time is ";
72    t.printUniversal();   // 00:00:00
73
74    cout << "\nThe initial standard time i
75    t.printStandard();    // 12:00:00 AM
76
77    t.setTime( 13, 27, 6 );   // change time
78
79    // output Time object t's new val
80    cout << "\n\nUniversal time after
81    t.printUniversal();   // 13:27:06
82
83    cout << "\nStandard time after se
84    t.printStandard();    // 1:27:06
85
86    t.setTime( 99, 99, 99 );  // attempt invalid settings
87
88    // output t's values after specifying invalid values
89    cout << "\n\nAfter attempting invalid settings:"
90         << "\nUniversal time: ";
91    t.printUniversal();   // 00:00:00
92
```

Invoke **public** member functions to print time.

Set data members using **public** member function.

Attempt to set data members to invalid values using **public** member function.

fig06_03.cpp
(4 of 5)



Outline

```
93     cout << "\nStandard time: ";
94     t.printStandard();    // 12:00:00 AM
95     cout << endl;
96
97     return 0;
98
99  } // end main
```

```
The initial universal time is 00:00:00
The initial standard time is 12:00:00 AM

Universal time after setTime is 13:27:06
Standard time after setTime is 1:27:06 PM

After attempting invalid settings:
Universal time: 00:00:00
Standard time: 12:00:00 AM
```

Data members set to **0** after attempting invalid settings.

fig06_03.cpp
(5 of 5)

fig06_03.cpp
output (1 of 1)

Implementing a `Time` Abstract Data Type with a `class`

- Destructors
  - Same name as class
    - Preceded with tilde (**~**)
  - No arguments
  - Cannot be overloaded
  - Performs “termination housekeeping”

Implementing a `Time` Abstract Data Type with a `class`

- Advantages of using classes
  - Simplify programming
  - Interfaces
    - Hide implementation
  - Software reuse
    - Composition (aggregation)
      - Class objects included as members of other classes
    - Inheritance
      - New classes derived from old

Class Scope and Accessing Class Members

- Class scope
  - Data members, member functions
  - Within class scope
    - Class members
      - Immediately accessible by all member functions
      - Referenced by name
  - Outside class scope
    - Referenced through handles
      - Object name, reference to object, pointer to object
- File scope
  - Nonmember functions

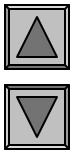
Class Scope and Accessing Class Members

- Function scope
  - Variables declared in member function
  - Only known to function
  - Variables with same name as class-scope variables
    - Class-scope variable “hidden”
      - Access with scope resolution operator (`::`)

        `ClassName::classVariableName`
  - Variables only known to function they are defined in
  - Variables are destroyed after function completion

Class Scope and Accessing Class Members

- Operators to access class members
  - Identical to those for **`struct`**s
  - Dot member selection operator (**`.`**)
    - Object
    - Reference to object
  - Arrow member selection operator (**`->`**)
    - Pointers



Outline

fig06_04.cpp
(1 of 2)

```
1  // Fig. 6.4: fig06_04.cpp
2  // Demonstrating the class member access operators . and ->
3  //
4  // CAUTION: IN FUTURE EXAMPLES WE AVOID PUBLIC DATA!
5  #include <iostream>
6
7  using std::cout;
8  using std::endl;
9
10 // class Count definition
11 class Count {
12
13 public:
14    int x;
15
16    void print()
17    {
18       cout << x << endl;
19    }
20
21 }; // end class Count
22
```

Data member **`x public`** to illustrate class member access operators; typically data members **`private`**.

Separating Interface from Implementation

- Separating interface from implementation
  - Advantage
    - Easier to modify programs
  - Disadvantage
    - Header files
      - Portions of implementation
        - Inline member functions
      - Hints about other implementation
        - private members
    - Can hide more with proxy class

Separating Interface from Implementation

- Header files
  - Class definitions and function prototypes
  - Included in each file using class
    - **`#include`**
  - File extension **`.h`**
- Source-code files
  - Member function definitions
  - Same base name
    - Convention
  - Compiled and linked

Controlling Access to Members

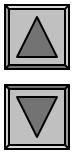
- Access modes
  - **`private`**
    - Default access mode
    - Accessible to member functions and **`friend`**s
  - **`public`**
    - Accessible to any function in program with handle to class object
  - **`protected`**
    - later

Controlling Access to Members

- Class member access
  - Default **`private`**
  - Explicitly set to **`private`**, **`public`**, **`protected`**
- **`struct`** member access
  - Default **`public`**
  - Explicitly set to **`private`**, **`public`**, **`protected`**
- Access to class's **`private`** data
  - Controlled with access functions (accessor methods)
    - Get function
      - Read **`private`** data
    - Set function
      - Modify **`private`** data

Access Functions and Utility Functions

- Access functions
  - **`public`**
  - Read/display data
  - Predicate functions
    - Check conditions
- Utility functions (helper functions)
  - **`private`**
  - Support operation of **`public`** member functions
  - Not intended for direct client use



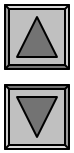
Outline

salesp.h (1 of 1)

```
1  // Fig. 6.9: salesp.h
2  // SalesPerson class definition.
3  // Member functions defined in salesp.cpp.
4  #ifndef SALESP_H
5  #define SALESP_H
6
7  class SalesPerson {
8
9  public:
10    SalesPerson();                  // construct
11    void getSalesFromUser();        // input sales from keyboard
12    void setSales( int, double );   // set sales for a month
13    void printAnnualSales();        // summarize
14
15 private:
16    double totalAnnualSales();      // utility function
17    double sales[ 12 ];             // 12 monthly sales figures
18
19 }; // end class SalesPerson
20
21 #endif
```

Set access function performs validity checks.

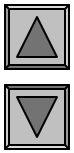
private utility function.



Outline

salesp.cpp (1 of 3)

```
1  // Fig. 6.10: salesp.cpp
2  // Member functions for class SalesPerson.
3  #include <iostream>
4
5  using std::cout;
6  using std::cin;
7  using std::endl;
8  using std::fixed;
9
10 #include <iomanip>
11
12 using std::setprecision;
13
14 // include SalesPerson class definition from salesp.h
15 #include "salesp.h"
16
17 // initialize elements of array sales to 0.0
18 SalesPerson::SalesPerson()
19 {
20    for ( int i = 0; i < 12; i++ )
21       sales[ i ] = 0.0;
22
23 } // end SalesPerson constructor
24
```

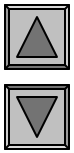


Outline

salesp.cpp (2 of 3)

```
25 // get 12 sales figures from the user at the keyboard
26 void SalesPerson::getSalesFromUser()
27 {
28    double salesFigure;
29
30    for ( int i = 1; i <= 12; i++ ) {
31       cout << "Enter sales amount for month " << i << ": ";
32       cin >> salesFigure;
33       setSales( i, salesFigure );
34
35    } // end for
36
37 } // end function getSalesFromUser
38
39 // set one of the 12 monthly sales figures; function subtracts
40 // one from month value for proper subscri
41 void SalesPerson::setSales( int month, dou
42 {
43    // test for valid month and amount values
44    if ( month >= 1 && month <= 12 && amount > 0 )
45       sales[ month - 1 ] = amount; // adjust for subscripts 0-11
46
47    else // invalid month or amount value
48       cout << "Invalid month or sales figure" << endl;
```

Set access function performs validity checks.

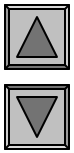


Outline

salesp.cpp (3 of 3)

```
49
50 } // end function setSales
51
52 // print total annual sales (with help of utility function)
53 void SalesPerson::printAnnualSales()
54 {
55    cout << setprecision( 2 ) << fixed
56         << "\nThe total annual sales are: $"
57         << totalAnnualSales() << endl; // call utility function
58
59 } // end function printAnnualSales
60
61 // private utility function to total annual sales
62 double SalesPerson::totalAnnualSales()
63 {
64    double total = 0.0;             // initialize total
65
66    for ( int i = 0; i < 12; i++ )  // summarize sales results
67       total += sales[ i ];
68
69    return total;
70
71 } // end function totalAnnualSales
```

`private` utility function to help function **`printAnnualSales`**; encapsulates logic of manipulating **`sales`** array.

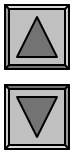


Outline

fig06_11.cpp
(1 of 1)

```
1  // Fig. 6.11: fig06_11.cpp
2  // Demonstrating a utility function.
3  // Compile this program with salesp.cpp
4
5  // include SalesPerson class definition from salesp.h
6  #include "salesp.h"
7
8  int main()
9  {
10    SalesPerson s;         // create SalesPerson object
11
12    s.getSalesFromUser();  // note simple sequential co
13    s.printAnnualSales();  // control structures in main
14
15    return 0;
16
17 } // end main
```

Simple sequence of member function calls; logic encapsulated in member functions.



Outline

```
Enter sales amount for month 1: 5314.76
Enter sales amount for month 2: 4292.38
Enter sales amount for month 3: 4589.83
Enter sales amount for month 4: 5534.03
Enter sales amount for month 5: 4376.34
Enter sales amount for month 6: 5698.45
Enter sales amount for month 7: 4439.22
Enter sales amount for month 8: 5893.57
Enter sales amount for month 9: 4909.67
Enter sales amount for month 10: 5123.45
Enter sales amount for month 11: 4024.97
Enter sales amount for month 12: 5923.92

The total annual sales are: $60120.59
```

fig06_11.cpp
output (1 of 1)

Initializing Class Objects: Constructors

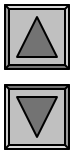
- Constructors
  - Initialize data members
    - Or can set later
  - Same name as class
  - No return type
- Initializers
  - Passed as arguments to constructor
  - In parentheses to right of class name before semicolon

```
Class-type ObjectName( value1,value2,…);
```

Using Default Arguments with Constructors

- Constructors
  - Can specify default arguments
  - Default constructors
    - Defaults all arguments

      OR
    - Explicitly requires no arguments
    - Can be invoked with no arguments
    - Only one per class

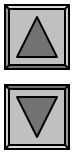


Outline

time2.h (1 of 1)

```
1  // Fig. 6.12: time2.h
2  // Declaration of class Time.
3  // Member functions defined in time2.cpp.
4
5  // prevent multiple inclusions of header file
6  #ifndef TIME2_H
7  #define TIME2_H
8
9  // Time abstract data type definition
10 class Time {
11
12 public:
13    Time( int = 0, int = 0, int = 0); // default constructor
14    void setTime( int, int, int ); // set hour, minute, second
15    void printUniversal();         // print universal-time format
16    void printStandard();          // print standard-time format
17
18 private:
19    int hour;     // 0 - 23 (24-hour clock format)
20    int minute;   // 0 - 59
21    int second;   // 0 - 59
22
23 }; // end class Time
24
25 #endif
```

Default constructor specifying all arguments.

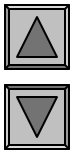


Outline

time2.cpp (1 of 3)

```
1  // Fig. 6.13: time2.cpp
2  // Member-function definitions for class Time.
3  #include <iostream>
4
5  using std::cout;
6
7  #include <iomanip>
8
9  using std::setfill;
10 using std::setw;
11
12 // include definition of class Time from time2.h
13 #include "time2.h"
14
15 // Time constructor initializes each data member to zero;
16 // ensures all Time objects start in a consistent state
17 Time::Time( int hr, int min, int sec )
18 {
19    setTime( hr, min, sec );  // validate and set time
20
21 } // end Time constructor
22
```

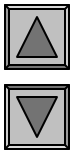
Constructor calls **`setTime`** to validate passed (or default) values.



Outline

time2.cpp (2 of 3)

```
23 // set new Time value using universal time, perform validity
24 // checks on the data values and set invalid values to zero
25 void Time::setTime( int h, int m, int s )
26 {
27    hour = ( h >= 0 && h < 24 ) ? h : 0;
28    minute = ( m >= 0 && m < 60 ) ? m : 0;
29    second = ( s >= 0 && s < 60 ) ? s : 0;
30
31 } // end function setTime
32
33 // print Time in universal format
34 void Time::printUniversal()
35 {
36    cout << setfill( '0' ) << setw( 2 ) << hour << ":"
37         << setw( 2 ) << minute << ":"
38         << setw( 2 ) << second;
39
40 } // end function printUniversal
41
```



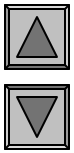
Outline

fig06_14.cpp
(1 of 2)

```
1  // Fig. 6.14: fig06_14.cpp
2  // Demonstrating a default constructor for class Time.
3  #include <iostream>
4
5  using std::cout;
6  using std::endl;
7
8  // include definition of class Time from time2.h
9  #include "time2.h"
10
11 int main()
12 {
13    Time t1;               // all arguments defaulted
14    Time t2( 2 );          // minute and second defaulted
15    Time t3( 21, 34 );     // second defaulted
16    Time t4( 12, 25, 42 ); // all values specified
17    Time t5( 27, 74, 99 ); // all bad values specified
18
19    cout << "Constructed with:\n\n"
20         << "all default arguments:\n  ";
21    t1.printUniversal();  // 00:00:00
22    cout << "\n  ";
23    t1.printStandard();   // 12:00:00 AM
24
```

Initialize **`Time`** objects using default arguments.

Initialize **`Time`** object with invalid values; validity checking will set values to **`0`**.



Outline

```
25    cout << "\n\nhour specified; default minute and second:\n  ";
26    t2.printUniversal();  // 02:00:00
27    cout << "\n  ";
28    t2.printStandard();   // 2:00:00 AM
29
30    cout << "\n\nhour and minute specified; default second:\n  ";
31    t3.printUniversal();  // 21:34:00
32    cout << "\n  ";
33    t3.printStandard();   // 9:34:00 PM
34
35    cout << "\n\nhour, minute, and second specified:\n  ";
36    t4.printUniversal();  // 12:25:42
37    cout << "\n  ";
38    t4.printStandard();   // 12:25:42 PM
39
40    cout << "\n\nall invalid values specified:\n  ";
41    t5.printUniversal();  // 00:00:00
42    cout << "\n  ";
43    t5.printStandard();   // 12:00:00 AM
44    cout << endl;
45
46    return 0;
47
48 } // end main
```

t5 constructed with invalid arguments; values set to **0**.

fig06_14.cpp
(2 of 2)

Destructors

- Destructors
  - Special member function
  - Same name as class
    - Preceded with tilde (~)
  - No arguments
  - No return value
  - Cannot be overloaded
  - Performs “termination housekeeping”
    - Before system reclaims object’s memory
      - Reuse memory for new objects
  - No explicit destructor
    - Compiler creates “empty” destructor”

When Constructors and Destructors Are Called

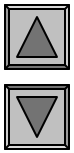
- Constructors and destructors
  - Called implicitly by compiler
- Order of function calls
  - Depends on order of execution
    - When execution enters and exits scope of objects
  - Generally, destructor calls reverse order of constructor calls

When Constructors and Destructors Are Called

- Order of constructor, destructor function calls
  - Global scope objects
    - Constructors
      - Before any other function (including **`main`**)
    - Destructors
      - When **`main`** terminates (or **`exit`** function called)
      - Not called if program terminates with **`abort`**
  - Automatic local objects
    - Constructors
      - When objects defined
        - Each time execution enters scope
    - Destructors
      - When objects leave scope
        - Execution exits block in which object defined
      - Not called if program ends with **`exit`** or **`abort`**

When Constructors and Destructors Are Called

- Order of constructor, destructor function calls
  - **`static`** local objects
    - Constructors
      - Exactly once
      - When execution reaches point where object defined
    - Destructors
      - When **`main`** terminates or **`exit`** function called
      - Not called if program ends with **`abort`**



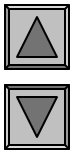
Outline

create.h (1 of 1)

```
1  // Fig. 6.15: create.h
2  // Definition of class CreateAndDestroy.
3  // Member functions defined in create.cpp.
4  #ifndef CREATE_H
5  #define CREATE_H
6
7  class CreateAndDestroy {
8
9  public:
10    CreateAndDestroy( int, char * );  // constructor
11    ~CreateAndDestroy();
12
13 private:
14    int objectID;
15    char *message;
16
17 }; // end class CreateAndDestroy
18
19 #endif
```

Constructor and destructor member functions.

`private` members to show order of constructor, destructor function calls.

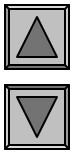


Outline

create.cpp (1 of 2)

```
1  // Fig. 6.16: create.cpp
2  // Member-function definitions for class CreateAndDestroy
3  #include <iostream>
4
5  using std::cout;
6  using std::endl;
7
8  // include CreateAndDestroy class definition from create.h
9  #include "create.h"
10
11 // constructor
12 CreateAndDestroy::CreateAndDestroy(
13    int objectNumber, char *messagePtr )
14 {
15    objectID = objectNumber;
16    message = messagePtr;
17
18    cout << "Object " << objectID << "   constructor runs   "
19         << message << endl;
20
21 } // end CreateAndDestroy constructor
22
```

Output message to demonstrate timing of constructor function calls.

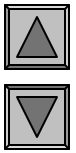


Outline

create.cpp (2 of 2)

```
23 // destructor
24 CreateAndDestroy::~CreateAndDestroy()
25 {
26    // the following line is for pedag
27    cout << ( objectID == 1 || objectI
28
29    cout << "Object " << objectID << "   destructor runs    "
30         << message << endl;
31
32 } // end ~CreateAndDestroy destructor
```

Output message to demonstrate timing of destructor function calls.



Outline

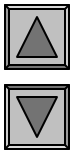
fig06_17.cpp
(1 of 3)

```
1  // Fig. 6.17: fig06_17.cpp
2  // Demonstrating the order in which constructors and
3  // destructors are called.
4  #include <iostream>
5
6  using std::cout;
7  using std::endl;
8
9  // include CreateAndDestroy class definition from create.h
10 #include "create.h"
11
12 void create( void );   // prototype
13
14 // global object
15 CreateAndDestroy first( 1, "(global before main)" );
16
17 int main()
18 {
19    cout << "\nMAIN FUNCTION: EXECUTION
20
21    CreateAndDestroy second( 2, "(local automatic in main)" );
22
23    static CreateAndDestroy third(
24       3, "(local static in main)" );
25
```

Create variable with global scope.

Create local automatic object.

Create **`static`** local object.



Outline

fig06_17.cpp
(2 of 3)

```
26    create();  // call function to create objects
27
28    cout << "\nMAIN FUNCTION: EXECUTION RESUMES" << endl;
29
30    CreateAndDestroy fourth(
31
32    cout << "\nMAIN FUNCTION: EXECUTION ENDS" << endl;
33
34    return 0;
35
36 } // end main
37
38 // function to create objects
39 void create( void )
40 {
41    cout << "\nCREATE FUNCTI
42
43    CreateAndDestroy fifth( 5
44
45    static CreateAndDestroy s
46       6, "(local static in c
47
48    CreateAndDestroy seventh(
49       7, "(local automatic in create)" );
50 cout << "\nCREATE FUNCTION: EXECUTION ENDS\" << endl;
52
53 } // end function create
```

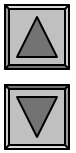
Create local automatic objects.

Create local automatic object.

Create local automatic object in function.

Create **`static`** local object in function.

Create local automatic object in function.



Outline

fig06_17.cpp
output (1 of 1)

```
Object 1   constructor runs   (global before main)

MAIN FUNCTION: EXECUTION BEGINS
Object 2   constructor runs   (local automatic in main)
Object 3   constructor runs   (local static in main)

CREATE FUNCTION: EXECUTION BEGINS
Object 5   constructor runs   (local automatic in create)
Object 6   constructor runs   (local static in create)
Object 7   constructor runs   (local automatic in create)

CREATE FUNCTION: EXECUTION ENDS
Object 7   destructor runs    (local automatic in create)
Object 5   destructor runs    (local automatic in create)

MAIN FUNCTION: EXECUTION RESUMES
Object 4   constructor runs   (local automatic in main)

MAIN FUNCTION: EXECUTION ENDS
Object 4   destructor runs    (local automatic in main)
Object 2   destructor runs    (local automatic in main)
Object 6   destructor runs    (local static in create)
Object 3   destructor runs    (local static in main)

Object 1   destructor runs    (global before main)
```

Local **`static`** object exists

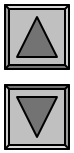
Global object constructed

Local automatic objects

Local **`static`** object constructed on first function call and destroyed after **`main`** execution ends.

Using *Set* and *Get* Functions

- Set functions
  - Perform validity checks before modifying **`private`** data
  - Notify if invalid values
  - Indicate with return values
- Get functions
  - “Query” functions
  - Control format of data returned



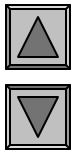
Outline

time3.h (1 of 2)

```
1   // Fig. 6.18: time3.h
2   // Declaration of class Time.
3   // Member functions defined in time3.cpp
4
5   // prevent multiple inclusions of header file
6   #ifndef TIME3_H
7   #define TIME3_H
8
9   class Time {
10
11  public:
12     Time( int = 0, int = 0, int = 0 );  // default constructor
13
14     // set functions
15     void setTime( int, int, int );  // set hour, minute, second
16     void setHour( int );   // set hour
17     void setMinute( int ); // set minute
18     void setSecond( int ); // set second
19
20     // get functions
21     int getHour();         // return hour
22     int getMinute();       // return minute
23     int getSecond();       // return second
24
```

Set functions.

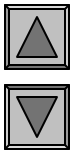
Get functions.



Outline

time3.h (2 of 2)

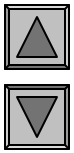
```
25    void printUniversal(); // output universal-time format
26    void printStandard();  // output standard-time format
27
28 private:
29    int hour;              // 0 - 23 (24-hour clock format)
30    int minute;            // 0 - 59
31    int second;            // 0 - 59
32
33 }; // end clas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



Outline

time3.cpp (1 of 4)

```
1  // Fig. 6.19: time3.cpp
2  // Member-function definitions for Time class.
3  #include <iostream>
4
5  using std::cout;
6
7  #include <iomanip>
8
9  using std::setfill;
10 using std::setw;
11
12 // include definition of class Time from time3.h
13 #include "time3.h"
14
15 // constructor function to initialize private data;
16 // calls member function setTime to set variables;
17 // default values are 0 (see class definition)
18 Time::Time( int hr, int min, int sec )
19 {
20    setTime( hr, min, sec );
21
22 } // end Time constructor
23
```



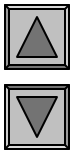
Outline

time3.cpp (2 of 4)

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

Call set functions to perform validity checking.

Set functions perform validity checks before modifying data.



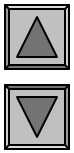
Outline

time3.cpp (3 of 4)

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

Set function performs validity checks before modifying data.

Get functions allow client to read data.



Outline

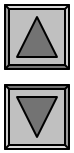
fig06_20.cpp

```
47 // add specified number of minutes to a Time object
48 void incrementMinutes( Time &tt, const int count )
49 {
50    cout << "Incrementing minute " << count
51         << " times:\nStart time: ";
52    tt.printStandard();
53
54    for ( int i = 0; i < count; i++ ) {
55       tt.setMinute( ( tt.getMinute() + 1 ) % 60 );
56
57       if ( tt.getMinute() == 0 )
58          tt.setHour( ( tt.getHour() + 1 ) % 24);
59
60       cout << "\nminute + 1: ";
61       tt.printStandard();
62
63    } // end for
64
65    cout << endl;
66
67 } // end function incrementMinutes
```

Using get functions to read data and set functions to modify data.

Subtle Trap: Returning a Reference to a `private` Data Member

- Reference to object
  - &pRef = p;
  - Alias for name of object
  - Lvalue
    - Can receive value in assignment statement
      - Changes original object
- Returning references
  - **`public`** member functions can return non-**`const`** references to **`private`** data members
    - Client able to modify **`private`** data members

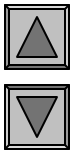


Outline

time4.h (1 of 1)

```
1  // Fig. 6.21: time4.h
2  // Declaration of class Time.
3  // Member functions defined in time4.cpp
4
5  // prevent multiple inclusions of header file
6  #ifndef TIME4_H
7  #define TIME4_H
8
9  class Time {
10
11 public:
12    Time( int = 0, int = 0, int = 0 );
13    void setTime( int, int, int );
14    int getHour();
15
16    int &badSetHour( int );  // DANGEROUS reference return
17
18 private:
19    int hour;
20    int minute;
21    int second;
22
23 }; // end class Time
24
25 #endif
```

Function to demonstrate effects of returning reference to **`private`** data member.

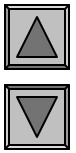


Outline

time4.cpp (2 of 2)

```
25 // return hour value
26 int Time::getHour()
27 {
28    return hour;
29
30 } // end function getHour
31
32 // POOR PROGRAMMING PRACTICE:
33 // Returning a reference to a private data member.
34 int &Time::badSetHour( int hh )
35 {
36    hour = ( hh >= 0 && hh < 24 )
37
38    return hour;  // DANGEROUS reference return
39
40 } // end function badSetHour
```

Return reference to **`private`** data member **`hour`**.



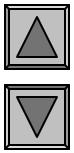
Outline

fig06_23.cpp
(1 of 2)

```
1  // Fig. 6.23: fig06_23.cpp
2  // Demonstrating a public member function that
3  // returns a reference to a private data member.
4  #include <iostream>
5
6  using std::cout;
7  using std::endl;
8
9  // include definition of class Time from time4.h
10 #include "time4.h"
11
12 int main()
13 {
14    Time t;
15
16    // store in hourRef the reference returned by badSe
17    int &hourRef = t.badSetHour( 20 );
18
19    cout << "Hour before modificat
20
21    // use hourRef to set invalid v
22    hourRef = 30;
23
24    cout << "\nHour after modification: " << t.getHour();
25
```

`badSetHour` returns reference to **`private`** data member **`hour`**.

Reference allows setting of **`private`** data member **`hour`**.



Outline

fig06_23.cpp
(2 of 2)

fig06_23.cpp
output (1 of 1)

```
26     // Dangerous: Function call that returns
27     // a reference can be used as an lvalue!
28     t.badSetHour( 12 ) = 74;
29
30     cout << "\n\n*********************************\n"
31          << "POOR PROGRAMMING PRACTIC
32          << "badSetHour as an lvalue,
33          << t.getHour()
34          << "\n*********************************" << endl;
35
36     return 0;
37
38  } // end main
```

Can use function call as lvalue to set invalid value.

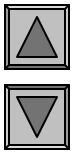
```
Hour before modification: 20
Hour after modification: 30

*********************************
POOR PROGRAMMING PRACTICE!!!!!!!
badSetHour as an lvalue, Hour: 74
*********************************
```

Returning reference allowed invalid setting of **`private`** data member **`hour`**.

Default Memberwise Assignment

- Assigning objects
  - Assignment operator (**=**)
    - Can assign one object to another of same type
    - Default: memberwise assignment
      - Each right member assigned individually to left member
- Passing, returning objects
  - Objects passed as function arguments
  - Objects returned from functions
  - Default: pass-by-value
    - Copy of object passed, returned
      - Copy constructor
        - Copy original values into new object



Outline

fig06_24.cpp
(1 of 3)

```
1  // Fig. 6.24: fig06_24.cpp
2  // Demonstrating that class objects can be assigned
3  // to each other using default memberwise assignment.
4  #include <iostream>
5
6  using std::cout;
7  using std::endl;
8
9  // class Date definition
10 class Date {
11
12 public:
13    Date( int = 1, int = 1, int = 1990 ); // default constructor
14    void print();
15
16 private:
17    int month;
18    int day;
19    int year;
20
21 }; // end class Date
22
```

Software Reusability

- Software reusability
  - Class libraries
    - Well-defined
    - Carefully tested
    - Well-documented
    - Portable
    - Widely available
  - Speeds development of powerful, high-quality software
    - Rapid applications development (RAD)
  - Resulting problems
    - Cataloging schemes
    - Licensing schemes
    - Protection mechanisms

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

- Principle of least privilege
  - Only allow modification of necessary objects
- Keyword **`const`**
  - Specify object not modifiable
  - Compiler error if attempt to modify **`const`** object
  - Example

```
const Time noon( 12, 0, 0 );
```

    - Declares **`const`** object **`noon`** of class **`Time`**
    - Initializes to 12

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

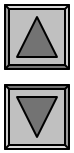
- **`const`** member functions
  - Member functions for **`const`** objects must also be **`const`**
    - Cannot modify object
  - Specify **`const`** in both prototype and definition
    - Prototype
      - After parameter list
    - Definition
      - Before beginning left brace

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

- Constructors and destructors
  - Cannot be **`const`**
  - Must be able to modify objects
    - Constructor
      - Initializes objects
    - Destructor
      - Performs termination housekeeping

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

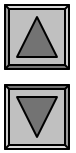
- Member initializer syntax
  - Initializing with member initializer syntax
    - Can be used for
      - All data members
    - Must be used for
      - **`const`** data members
      - Data members that are references



Outline

fig07_04.cpp
(1 of 3)

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



Outline

fig07_04.cpp
(2 of 3)

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

Member initializer list separated by colon.

ncrement as **const**

Member initializer syntax can be

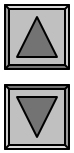
me

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

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

Composition: Objects as Members of Classes

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

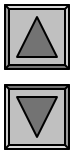


Outline

date1.h (1 of 1)

```
1  // Fig. 7.6: date1.h
2  // Date class definition.
3  // Member functions defined in date1.cpp
4  #ifndef DATE1_H
5  #define DATE1_H
6
7  class Date {
8
9  public:
10    Date( int = 1, int = 1, int = 
11    void print() const;  // print 
12    ~Date();  // provided to confirm destruction order
13
14 private:
15    int month;  // 1-12 (January-December)
16    int day;    // 1-31 based on month
17    int year;   // any year
18
19    // utility function to test proper day for month and year
20    int checkDay( int ) const;
21
22 }; // end class Date
23
24 #endif
```

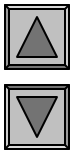
Note no constructor with parameter of type **`Date`**. Recall compiler provides default copy constructor.



Outline

date1.cpp (1 of 3)

```
1  // Fig. 7.7: date1.cpp
2  // Member-function definitions for class Date.
3  #include <iostream>
4
5  using std::cout;
6  using std::endl;
7
8  // include Date class definition from date1.h
9  #include "date1.h"
10
11 // constructor confirms proper value for month; calls
12 // utility function checkDay to confirm proper value for day
13 Date::Date( int mn, int dy, int yr )
14 {
15    if ( mn > 0 && mn <= 12 )  // validate the month
16       month = mn;
17
18    else {                     // invalid month set to 1
19       month = 1;
20       cout << "Month " << mn << " invalid. Set to month 1.\n";
21    }
22
23    year = yr;                 // should validate yr
24    day = checkDay( dy );      // validate the day
25
```

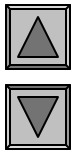


Outline

employee1.h (1 of 2)

```
1  // Fig. 7.8: employee1.h
2  // Employee class definition.
3  // Member functions defined in employee1.cpp.
4  #ifndef EMPLOYEE1_H
5  #define EMPLOYEE1_H
6
7  // include Date class definition from date1.h
8  #include "date1.h"
9
10 class Employee {
11
12 public:
13    Employee(
14       const char *, const char *, const Date &, const Date & );
15
16    void print() const;
17    ~Employee();  // provided to confirm destruction order
18
19 private:
20    char firstName[ 25 ];
21    char lastName[ 25 ];
22    const Date birthDate;  // composition: member object
23    const Date hireDate;   // composition: member object
24
25 }; // end class Employee
```

Using composition; **`Employee`** object contains **`Date`** objects as data members.



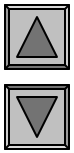
Outline

```
26
27  #endif
```

employee1.h (2 of 2)

employee1.cpp
(1 of 3)

```
1   // Fig. 7.9: employee1.cpp
2   // Member-function definitions for class Employee.
3   #include <iostream>
4
5   using std::cout;
6   using std::endl;
7
8   #include <cstring>      // strcpy and strlen prototypes
9
10  #include "employee1.h"  // Employee class definition
11  #include "date1.h"      // Date class definition
12
```



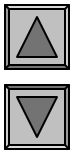
Outline

employee1.cpp
(2 of 3)

```
13 // constructor uses member initializer list to pass initializer
14 // values to constructors of member objects birthDate and
15 // hireDate [Note: This invokes the so-called "default copy
16 // constructor" which the C++ compiler provides implicitly.]
17 Employee::Employee( const char *first, const char *last,
18    const Date &dateOfBirth, const Date &dateOfHire )
19    : birthDate( dateOfBirth ),  // initialize birthDate
20      hireDate( dateOfHire )     // initialize hireDate
21 {
22    // copy first into firstName and be sur
23    int length = strlen( first );
24    length = ( length < 25 ? length : 24 );
25    strncpy( firstName, first, length );
26    firstName[ length ] = '\0';
27
28    // copy last into lastName and be sure that it fits
29    length = strlen( last );
30    length = ( length < 25 ? length : 24 );
31    strncpy( lastName, last, length );
32    lastName[ length ] = '\0';
33
34    // output Employee object to show when constructor is called
35    cout << "Employee object constructor: "
36         << firstName << ' ' << lastName << endl;
37
```

Member initializer syntax to initialize **`Date`** data members **`birthDate`** and **`hireDate`**; compiler uses default copy constructor.

Output to show timing of constructors.

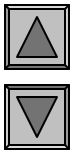


Outline

employee1.cpp
(3 of 3)

```
38 } // end Employee constructor
39
40 // print Employee object
41 void Employee::print() const
42 {
43    cout << lastName << ", " << firstName << "\nHired: ";
44    hireDate.print();
45    cout << "  Birth date: ";
46    birthDate.print();
47    cout << endl;
48
49 } // end function print
50
51 // output Employee object to show when it
52 Employee::~Employee()
53 {
54    cout << "Employee object destructor: "
55         << lastName << ", " << firstName << endl;
56
57 } // end destructor ~Employee
```

Output to show timing of destructors.

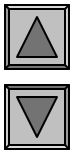


Outline

fig07_10.cpp
(1 of 1)

```
1  // Fig. 7.10: fig07_10.cpp
2  // Demonstrating composition--an object with member objects.
3  #include <iostream>
4
5  using std::cout;
6  using std::endl;
7
8  #include "employee1.h"  // Employee class definition
9
10 int main()
11 {
12    Date birth( 7, 24, 1949 );
13    Date hire( 3, 12, 1988 );
14    Employee manager( "Bob", "Jones", birth, hire );
15
16    cout << '\n';
17    manager.print();
18
19    cout << "\nTest Date constructor with invalid values:\n";
20    Date lastDayOff( 14, 35, 1994 );  // invalid month and day
21    cout << endl;
22
23    return 0;
24
25 } // end main
```

Create **`Date`** objects to pass to **`Employee`** constructor.



Outline

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

Jones, Bob
Hired: 3/12/1988  Birth date: 7/24/1949

Test Date constructor with invalid values:
Month 14 invalid. Set to month 1.
Day 35 invalid. Set to day 1.
Date object constructor for date 1/1/1994

Date object destructor for date 1/1/1994
Employee object destructor: Jones, 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
```

Note two additional **Date** objects constructed; no output since default copy constructor used.

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Destructor for **Employee**'s

Destructor for **Employee**'s

Destructor for **Date** object

Destructor for **Date** object **birth**.