Operator Overloading in C++

Systems Programming

Operator Overloading

- Fundamentals of Operator Overloading
- Restrictions on Operator Overloading
- Operator Functions as Class Members vs. Global Functions
- Overloading Stream Insertion and Stream Extraction Operators

Operator Overloading

- Overloading Unary Operators
- Overloading Binary Operators
- Case Study: Array Class
- Case Study: String Class
- Case Study: A Date Class
- Standard Library Class string
- Explicit Constructors

Introduction

- Users can use operators with user-defined types (e.g.,with objects {operator overloading}).
  - Clearer than function calls for certain classes.
  - C++ makes *operators sensitive to context*.

Examples:

<<

- Stream insertion, bitwise left-shift

+

- Performs arithmetic on multiple items (integers, floats, pointers)

Operator Overloading

- An operator is overloaded by writing:
  - a non-static member function definition

  or

  - a global function definition

  where

  the function name becomes the keyword **operator** followed by the symbol for the operation being overloaded.

Operator Overloading

- Types for operator overloading
  - Built in (int, char) or user-defined (classes)
  - Can use existing operators with user-defined types.
  - **Cannot create new operators!**
- Overloading operators
  - Create a function for the class.
  - Name of operator function.
    - Keyword **operator** followed by the symbol

Example

function name **operator+** for the addition operator **+**

Operator Overloading

- To use an operators on a class object:
  - The operator must be overloaded for that class.
- Three Exceptions: {overloading not required}
  - Assignment operator (=)
    - Memberwise assignment between objects
    - Dangerous for classes with pointer members!!
  - Address operator (&)
    - Returns address of the object in memory.
  - Comma operator (,)
    - Evaluates expression to its left then the expression to its right.
    - Returns the value of the expression to its right.
- Overloading provides concise notation

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

vs.

```
object2 = object2 + object1;
```

Restrictions on Operator Overloading

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

Fig. 22.1 Operators that can be overloaded.

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

Fig. 22.1 Operators that cannot be overloaded.

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

Software Engineering Observation 22.2

- At least one argument of an operator function must be an object or reference of a user-defined type.
- This prevents programmers from changing how operators work on fundamental types.

22.4 Operator Functions as Class Members vs. Global Members

- Operator functions as member functions:
  - Leftmost object must be of same class as operator function.
  - Use **this** keyword to implicitly get left operand argument.
  - Operators **()**, **[]**, **->** or any assignment operator must be overloaded as a **class member function**.
  - Called when
    - Left operand of binary operator is of this class.
    - Single operand of unary operator is of this class.

22.4 Operator Functions as Class Members vs. Global Members

- Operator functions as global functions
  - Need parameters for both operands.
  - Can have object of different class than operator.
  - Can be made a **friend** to access **private** or **protected** data.

Overloading Stream Insertion and Stream Extraction Operators

- Overloaded **<<** operator used where
  - Left operand of type **ostream &**
    - Such as **cout** object in **cout << classObject**
  - To use the operator in this manner where the right operand is an object of a user-defined class, it must be overloaded as a **global function**.
  - Similarly, overloaded **>>** has left operand of **istream &**
  - Thus, both must be global functions.

Commutative operators

- May want + to be commutative
  - So both "a + b" and "b + a" work.
- Suppose we have two different classes
  - Overloaded operator can only be member function when its class is on left.

    HugeIntClass + long int
    - Can be member function
  - For the other way, you need a global overloaded function.

    long int + HugeIntClass

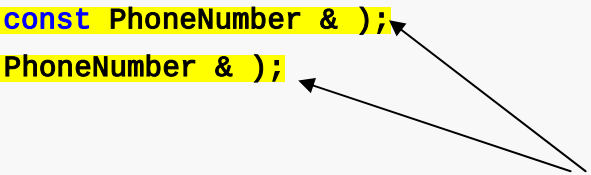
22.5 Overloading Stream Insertion and Stream Extraction Operators

- << and >> operators
  - Already overloaded to process each built-in type (pointers and strings).
  - Can also process a user-defined class.
    - Overload using global, friend functions
- Example program
  - Class PhoneNumber
    - Holds a telephone number
  - Prints out formatted number automatically.

```
(123) 456-7890
```

Overload Stream Insertion and Extraction Operators

```
1  // Fig. 22.3: PhoneNumber.h
2  // PhoneNumber class definition
3  #ifndef PHONENUMBER_H
4  #define PHONENUMBER_H
5
6  #include <iostream>
7  using std::ostream;
8  using std::istream;
9
10 #include <string>
11 using std::string;
12
13 class PhoneNumber
14 {
15    friend ostream &operator<<( ostream &, const PhoneNumber & );
16    friend istream &operator>>( istream &, PhoneNumber & );
17 private:
18    string areaCode; // 3-digit area code
19    string exchange; // 3-digit exchange
20    string line; // 4-digit line
21 }; // end class PhoneNumber
22
23 #endif
```



Notice function prototypes for overloaded operators >> and << (must be global, friend functions)

Overload Stream Insertion and Extraction Operators

```
1  // Fig. 22.4: PhoneNumber.cpp
2  // Overloaded stream insertion and stream extraction operators
3  // for class PhoneNumber.
4  #include <iomanip>
5  using std::setw;
6
7  #include "PhoneNumber.h"
8
9  // overloaded stream insertion operator; cannot be
10 // a member function if we would like to invoke it with
11 // cout << somePhoneNumber;
12 ostream &operator<<( ostream &output, const PhoneNumber &number )
13 {
14    output << "(" << number.areaCode << ") "
15       << number.exchange << "-" << number.line;
16    return output; // enables cout << a << b << c;
17 } // end function operator<<
```

Allows cout << phone; to be interpreted as:
operator<<(cout, phone);

Display formatted phone number

Overload Stream Insertion and Extraction Operators

```
18
19 // overloaded stream extraction operator; cannot be
20 // a member function if we would like to invoke it with
21 // cin >> somePhoneNumber;
22 istream &operator>>( istream &input, PhoneNumber &number )
23 {
24    input.ignore(); // skip (
25    input >> setw( 3 ) >> number.areaCode; // input area code
26    input.ignore( 2 ); // skip ) and space
27    input >> setw( 3 ) >> number.exchange; // input exchange
28    input.ignore(); // skip dash (-)
29    input >> setw( 4 ) >> number.line; // input line
30    return input; // enables cin >> a >> b >> c;
31 } // end function operator>>
```

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

Input each portion of phone number separately

Overload Stream Insertion and Extraction Operators

```
1  // Fig. 22.5: fig22_05.cpp
2  // Demonstrating class PhoneNumber's overloaded stream insertion
3  // and stream extraction operators.
4  #include <iostream>
5  using std::cout;
6  using std::cin;
7  using std::endl;
8
9  #include "PhoneNumber.h"
10
11 int main()
12 {
13    PhoneNumber phone; // create object phone
14
15    cout << "Enter phone number in the form (123) 456-7890:" << endl;
16
17    // cin >> phone invokes operator>> by implicitly issuing
18    // the global function call operator>>( cin, phone )
19    cin >> phone;
20
21    cout << "The phone number entered was: ";
22
23    // cout << phone invokes operator<< by implicitly issuing
24    // the global function call operator<<( cout, phone )
25    cout << phone << endl;
26    return 0;
27 } // end main
```

Testing overloaded >> and << operators to input and output a PhoneNumber object

Overload Stream Insertion and Extraction Operators

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

22.6 Overloading Unary Operators

- Overloading unary operators of a class:
  - Can overload as a non-static member function with no arguments.
  - Can overload as a global function with one argument.
    - Argument must be class object or reference to class object.
  - Remember, static functions only access static data.

22.6 Overloading Unary Operators

Example

Overload ! to test for empty string

- Consider the expression !s in which s is an object of class String. For !s the compiler generates the call s.operator!( )

Namely, since it is a non-static member function, it needs no arguments:

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

- If a global function, it needs one argument:
  - bool operator!(const String &)
  - !s becomes operator!(s)
  ```

22.7 Overloading Binary Operators

- Overloading binary operators
  - Non-static member function with one argument.

or

  - Global function with two arguments:
    - One argument must be class object or reference to a class object.

22.7 Overloading Binary Operators

- If a non-`static` member function, it needs one argument.
  - ```
    class String
    {
    public:
       const String & operator+=( const String & );
       …
    };
    ```
  - `y += z` becomes `y.operator+=( z )`

Clear example of conciseness of operator overload

- If a global function, it needs two arguments.
  - `const String &operator+=( String &, const String & );`
  - `y += z` becomes `operator+=( y, z )`
    ```

Overloading Operators

- On the previous slide, y and z are assumed to be String-class objects or references to String-class objects.
- There are two ways to pass arguments to the global function, either with an argument that is an object (this requires a copy of the object) or with an argument that is a reference to an object (this means the side effects of the function called to implement the overloaded operator can side-effect this object that is called-by-reference!)

22.8 Case Study: Array Class

- Problems with pointer-based arrays in C++:
  - No range checking.
  - Cannot be compared meaningfully with ==
  - No array assignment (array names are const pointers).
  - If array passed to a function, size must be passed as a separate argument.

{Basic point of this chapter – by using C++ classes and operator overloading, one can significantly change the capabilities of the built in array type.}

Case Study: Array Class

Case Study: Implement an Array class with:

1. Range checking
2. Array assignment (=)
3. Arrays that know their own size.
4. Outputting/inputting entire arrays with << and >>
5. Array comparisons with == and !=

Case Study: Array Class

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

    `Array newArray( oldArray );` or

    `Array newArray = oldArray;` (both are identical)
    - `newArray` is a copy of `oldArray`.

Case Study: Array Class

- Prototype for class Array

```
Array( const Array & );
```

  - Must take reference
    - Otherwise, the argument will be passed by value…
    - Which tries to make copy by calling copy constructor…
      - This yields an infinite loop!

Case Study: Array Class


```
1  // Fig. 22.6: Array.h
2  // Array class for storing arrays of integers.
3  #ifndef ARRAY_H
4  #define ARRAY_H
5
6  #include <iostream>
7  using std::ostream;
8  using std::istream;
9
10 class Array
11 {
12    friend ostream &operator<<( ostream &, const Array & );
13    friend istream &operator>>( istream &, Array & );
14 public:
15    Array( int = 10 ); // default constructor
16    Array( const Array & ); // copy constructor
17    ~Array(); // destructor
18    int getSize() const; // return size
19
20    const Array &operator=( const Array & ); // assignment operator
21    bool operator==( const Array & ) const; // equality operator
22
23    // inequality operator; returns opposite of == operator
24    bool operator!=( const Array &right ) const
25    {
26       return ! ( *this == right ); // invokes Array::operator==
27    } // end function operator!=
```

Most operators overloaded as member functions (except << and >> which must be global functions)

Prototype for copy constructor

!= operator simply returns opposite of == operator – only need to define the == operator

Case Study: Array Class

```
28
29    // subscript operator for non-const objects returns modifiable lvalue
30    int &operator[]( int );
31
32    // subscript operator for const objects returns rvalue
33    int operator[]( int ) const;
34 private:
35    int size; // pointer-based array size
36    int *ptr; // pointer to first element of pointer-based array
37 }; // end class Array
38
39 #endif
```

Operators for accessing specific elements of Array object

Note: An example of pointer data member

Case Study: Array Class

```
1  // Fig 22.7: Array.cpp
2  // Member-function definitions for class Array
3  #include <iostream>
4  using std::cerr;
5  using std::cout;
6  using std::cin;
7  using std::endl;
8
9  #include <iomanip>
10 using std::setw;
11
12 #include <cstdlib> // exit function prototype
13 using std::exit;
14
15 #include "Array.h" // Array class definition
16
17 // default constructor for class Array (default size 10)
18 Array::Array( int arraySize )
19 {
20    size = ( arraySize > 0 ? arraySize : 10 ); // validate arraySize
21    ptr = new int[ size ]; // create space for pointer-based array
22
23    for ( int i = 0; i < size; i++ )
24       ptr[ i ] = 0; // set pointer-based array element
25 } // end Array default constructor
```

Case Study: Array Class

```
26
27 // copy constructor for class Array;
28 // must receive a reference to prevent infinite recursion
29 Array::Array( const Array &arrayToCopy )
30    : size( arrayToCopy.size )
31 {
32    ptr = new int[ size ]; // create space for pointer-based array
33
34    for ( int i = 0; i < size; i++ )
35       ptr[ i ] = arrayToCopy.ptr[ i ]; // copy into object
36 } // end Array copy constructor
37
38 // destructor for class Array
39 Array::~Array()
40 {
41    delete [] ptr; // release pointer-based array space
42 } // end destructor
43
44 // return number of elements of Array
45 int Array::getSize() const
46 {
47    return size; // number of elements in Array
48 } // end function getSize
```

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

Case Study: Array Class

```
49
50 // overloaded assignment operator;
51 // const return avoids: ( a1 = a2 ) = a3
52 const Array &Array::operator=( const Array &right )
53 {
54    if ( &right != this ) // avoid self-assignment
55    {
56       // for Arrays of different sizes, deallocate original
57       // left-side array, then allocate new left-side array
58       if ( size != right.size )
59       {
60          delete [] ptr; // release space
61          size = right.size; // resize this object
62          ptr = new int[ size ]; // create space for array copy
63       } // end inner if
64
65       for ( int i = 0; i < size; i++ )
66          ptr[ i ] = right.ptr[ i ]; // copy array into object
67    } // end outer if
68
69    return *this; // enables x = y = z, for example
70 } // end function operator=
```

Want to avoid self assignment

This would be dangerous if this is the same Array as right

Case Study: Array Class

```
71
72 // determine if two Arrays are equal and
73 // return true, otherwise return false
74 bool Array::operator==( const Array &right ) const
75 {
76    if ( size != right.size )
77       return false; // arrays of different number of elements
78
79    for ( int i = 0; i < size; i++ )
80       if ( ptr[ i ] != right.ptr[ i ] )
81          return false; // Array contents are not equal
82
83    return true; // Arrays are equal
84 } // end function operator==
85
86 // overloaded subscript operator for non-const Arrays;
87 // reference return creates a modifiable lvalue
88 int &Array::operator[]( int subscript )
89 {
90    // check for subscript out-of-range error
91    if ( subscript < 0 || subscript >= size )
92    {
93       cerr << "\nError: Subscript " << subscript
94          << " out of range" << endl;
95       exit( 1 ); // terminate program; subscript out of range
96    } // end if
97
98    return ptr[ subscript ]; // reference return
99 } // end function operator[]
```

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

Case Study: Array Class

```
100
101// overloaded subscript operator for const Arrays
102// const reference return creates an rvalue
103int Array::operator[]( int subscript ) const
104{
105   // check for subscript out-of-range error
106   if ( subscript < 0 || subscript >= size )
107   {
108      cerr << "\nError: Subscript " << subscript
109         << " out of range" << endl;
110      exit( 1 ); // terminate program; subscript out of range
111   } // end if
112
113   return ptr[ subscript ]; // returns copy of this element
114} // end function operator[]
115
116// overloaded input operator for class Array;
117// inputs values for entire Array
118istream &operator>>( istream &input, Array &a )
119{
120   for ( int i = 0; i < a.size; i++ )
121      input >> a.ptr[ i ];
122
123   return input; // enables cin >> x >> y;
124} // end function
```

Case Study: Array Class

```
125
126// overloaded output operator for class Array
127ostream &operator<<( ostream &output, const Array &a )
128{
129   int i;
130
131   // output private ptr-based array
132   for ( i = 0; i < a.size; i++ )
133   {
134      output << setw( 12 ) << a.ptr[ i ];
135
136      if ( ( i + 1 ) % 4 == 0 ) // 4 numbers per row of output
137         output << endl;
138   } // end for
139
140   if ( i % 4 != 0 ) // end last line of output
141      output << endl;
142
143   return output; // enables cout << x << y;
144} // end function operator<<
```

Case Study: Array Class

```
1  // Fig. 22.8: fig22_08.cpp
2  // Array class test program.
3  #include <iostream>
4  using std::cout;
5  using std::cin;
6  using std::endl;
7
8  #include "Array.h"
9
10 int main()
11 {
12    Array integers1( 7 ); // seven-element Array
13    Array integers2; // 10-element Array by default
14
15    // print integers1 size and contents
16    cout << "Size of Array integers1 is "
17       << integers1.getSize()
18       << "\nArray after initialization:\n" << integers1;
19
20    // print integers2 size and contents
21    cout << "\nSize of Array integers2 is "
22       << integers2.getSize()
23       << "\nArray after initialization:\n" << integers2;
24
25    // input and print integers1 and integers2
26    cout << "\nEnter 17 integers:" << endl;
27    cin >> integers1 >> integers2;
```

Retrieve number of elements in Array

Use overloaded >> operator to input

Case Study: Array Class

```
28
29    cout << "\nAfter input, the Arrays contain:\n"
30       << "integers1:\n" << integers1
31       << "integers2:\n" << integers2;
32
33    // use overloaded inequality (!=) operator
34    cout << "\nEvaluating: integers1 != integers2" << endl;
35
36    if ( integers1 != integers2 )
37       cout << "integers1 and integers2 are not equal" << endl;
38
39    // create Array integers3 using integers1 as an
40    // initializer; print size and contents
41    Array integers3( integers1 ); // invokes copy constructor
42
43    cout << "\nSize of Array integers3 is "
44       << integers3.getSize()
45       << "\nArray after initialization:\n" << integers3;
46
47    // use overloaded assignment (=) operator
48    cout << "\nAssigning integers2 to integers1:" << endl;
49    integers1 = integers2; // note target Array is smaller
50
51    cout << "integers1:\n" << integers1
52       << "integers2:\n" << integers2;
53
54    // use overloaded equality (==) operator
55    cout << "\nEvaluating: integers1 == integers2" << endl;
```

Use overloaded << operator to output

Use overloaded != operator to test for inequality

Use copy constructor

Use overloaded = operator to assign

Case Study: Array Class

```
56
57    if ( integers1 == integers2 )
58       cout << "integers1 and integers2 are equal" << endl;
59
60    // use overloaded subscript operator to create rvalue
61    cout << "\nintegers1[5] is " << integers1[ 5 ];
62
63    // use overloaded subscript operator to create lvalue
64    cout << "\n\nAssigning 1000 to integers1[5]" << endl;
65    integers1[ 5 ] = 1000;
66    cout << "integers1:\n" << integers1;
67
68    // attempt to use out-of-range subscript
69    cout << "\nAttempt to assign 1000 to integers1[15]" << endl;
70    integers1[ 15 ] = 1000; // ERROR: out of range
71    return 0;
72 } // end main
```

Use overloaded == operator to test for equality

Use overloaded [] operator to access individual integers, with range-checking

Case Study: Array Class

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

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

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

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

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

Case Study: Array Class

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

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

Evaluating: integers1 == integers2
integers1 and integers2 are equal

integers1[5] is 13

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

Attempt to assign 1000 to integers1[15]

Error: Subscript 15 out of range
```

Summary

- Covered operator overloading basics.
- Reviewed operator overloading restrictions.
- Explained when to use class member functions and when to use global functions to implement operator overloading.
- Discussed overloading stream insertion and stream extraction operators and did one simple example of overloading.

Summary

- Went through overloading unary and binary operators.
- Looked at operator overloading in an elaborate case study involving an Array class.