Programming in Modern C++

Module M18: Overloading Operator for User-Defined Types: Part 1

Partha Pratim Das

Department of Computer Science and Engineering
Indian Institute of Technology, Kharagpur

ppd@cse.iitkgp.ac.in

All url's in this module have been accessed in September, 2021 and found to be functional

Module Recap

- Introduced the notion of `friend` function
- Introduced the notion of `friend` class
- Studied the use of `friend` function and `friend` class with examples
- `friend` introduces visibility hole by breaking encapsulation – should be used with care

Module Objectives

- Understand how to overload operators for a user-defined type (class)
- Understand the aspects of overloading by global function and member function

Module Outline

1. Operator Function
   - Non-Member Function
   - Member Function
   - Operator Overloading Rules
2. Using Global Function
   - `public` data members
   - `private` data members
3. Using Member Function
   - `operator+`
   - `operator=`
   - Unary Operators
4. Module Summary

Operator Function

How can operator functions help?

- We have seen how overloading `operator+` a C-string wrapped in `struct` allows us a compact notation for concatenation of two strings (Module 09)
- We have seen how overloading `operator=` can define the deep / shallow copy for a UDT and / or help with user-defined copy semantics (Module 14)
- In general, operator overloading helps us to build complete algebra for UDT's much in the same line as is available for built-in types:
  - **Complex type**: Add (`+`), Subtract (`-`), Multiply (`*`), Divide (`/`), Conjugate (`!`), Compare (`==, !=, ...`), etc.
  - **Fraction type**: Add (`+`), Subtract (`-`), Multiply (`*`), Divide (`/`), Normalize (unary `*`), Compare (`==, !=, ...`), etc.
  - **Matrix type**: Add (`+`), Subtract (`-`), Multiply (`*`), Divide (`/`), Invert (`!`), Compare (`==`), etc.
  - **Set type**: Union (`+`), Difference (`-`), Intersection (`*`), Subset (`< <=`), Superset (`> >=`), Compare (`==, !=`), etc.
  - **Direct IO**: read (`<<`) and write (`>>`) for all types
- Advanced examples include:
  - **Smart Pointers**: De-reference (unary `*`), Indirection (`->`), Copy (`=`), Compare (`==, !=`), etc.
  - **Function Objects or Functors**: Invocation (`()`)

Operator Functions in C++: RECAP (Module 9)

- Introduces a new keyword: `operator`
- Every operator is associated with an operator function that defines its behavior

Operator Expression	Operator Function
`a + b`	`operator+(a, b)`
`a = b`	`operator=(a, b)`
`c = a + b`	`operator=(c, operator+(a, b))`

- Operator functions are implicit for predefined operators of built-in types and cannot be redefined
- An operator function may have a signature as:

```
MyType a, b; // An enum or struct

// Operator function
MyType operator+(const MyType&, const MyType&);

a + b // Calls operator+(a, b)
```

- C++ allows users to define an operator function and overload it

Non-Member Operator Function

- A non-member operator function may be a
  - Global Function
  - `friend` Function
- **Binary Operator:**

```
MyType a, b; // An enum, struct or class
MyType operator+(const MyType&, const MyType&);        // Global
friend MyType operator+(const MyType&, const MyType&); // Friend
```

- **Unary Operator:**

```
MyType operator++(const MyType&);        // Global
friend MyType operator++(const MyType&); // Friend
```

- **Note:** The parameters may not be constant and may be passed by value. The return may also be by reference and may be constant
- **Examples:**

Operator Expression	Operator Function
`a + b`	`operator+(a, b)`
`a = b`	`operator=(a, b)`
`++a`	`operator++(a)`
`a++`	`operator++(a, int)  Special Case`
`c = a + b`	`operator=(c, operator+(a, b))`

Member Operator Function

- **Binary Operator:**

```
MyType a, b;                          // MyType is a class
MyType operator+(const MyType&); // Operator function
```

- The left operand is the invoking object – right is taken as a parameter
- **Unary Operator:**

```
MyType operator-();      // Operator function for Unary minus
MyType operator++();     // For Pre-Incrementer
MyType operator++(int); // For post-Incrementer
```

- The only operand is the invoking object
- **Note:** The parameters may not be constant and may be passed by value. The return may also be by reference and may be constant
- **Examples:**

Operator Expression	Operator Function
a + b	a.operator+(b)
a = b	a.operator=(b)
++a	a.operator++()
a++	a.operator++(int) // Special Case
c = a + b	c.operator =(a.operator+(b))

Operator Overloading – Summary of Rules: RECAP (Module 9)

- No new operator such as `**`, `<>`, or `&|` can be defined for overloading
- Intrinsic properties of the overloaded operator cannot be change
  - *Preserves arity*
  - *Preserves precedence*
  - *Preserves associativity*
- These operators *can be overloaded*:

```
[] + - * / % ^ & | ~ ! = += -= *= /= %= ^= &= |=
<< >> >>= <<= == != < > <= >= && || ++ -- , ->* -> ( ) [ ]
```

- The operators `::` (scope resolution), `.` (member access), `.*` (member access through pointer to member), `sizeof`, and `?:` (ternary conditional) *cannot be overloaded*
- The overloads of operators `&&`, `||`, and `,` (comma) *lose their special properties*: short-circuit evaluation and sequencing
- The overload of `operator->` must either return a raw pointer or return an object (by reference or by value), for which `operator->` is in turn overloaded
- For a member operator function, invoking object is passed implicitly as the left operand but the right operand is passed explicitly
- For a non-member operator function (Global/friend) operands are always passed explicitly

Using Global Function

Program 18.01: Using Global Function: public Data members (Unsafe)

Overloading + for complex addition

```
#include <iostream>
using namespace std;
struct complx { // public data member
    double re, im;
} ;
complx operator+ (complx &a, complx &b) {
     complx r;
     r.re = a.re + b.re;
     r.im = a.im + b.im;
     return r;
}
int main() { complx d1 , d2 , d;
    d1.re = 10.5; d1.im = 12.25;
    d2.re = 20.5; d2.im = 30.25;
    d = d1 + d2; // Overload operator +
    cout << "Real:" << d.re << ", ";
    cout << "Imag:" << d.im;
}
```

- **Output**: Real: 31, Imag: 42.5
- **operator+** is overloaded to perform addition of two complex numbers which are of **struct complx** type

Overloading + for string cat

```
#include <iostream>
#include <cstdlib>
#include <cstring>
using namespace std;
typedef struct _String { char *str; } String;
String operator+(const String& s1, const String& s2) {
    String s;
    s.str = (char *) malloc(strlen(s1.str) +
                            strlen(s2.str) + 1);
    strcpy(s.str, s1.str); strcat(s.str, s2.str);
    return s;
}
int main() { String fName, lName, name;
    fName.str = strdup("Partha ");
    lName.str = strdup("Das");
    name = fName + lName; // Overload operator +
    cout << "First Name: " << fName.str << endl;
    cout << "Last Name: " << lName.str << endl;
    cout << "Full Name: " << name.str << endl;
}
```

- **Output**: First Name: Partha, Last Name: Das, Full name: Partha Das
- **operator+** is overloaded to perform concat of first name and last to form full name. The data type is **String**

Program 18.02: Using Global Function: private Data members (Safe)


```
#include <iostream>
using namespace std;
class Complex { // Private data members
    double re, im;
public:
    Complex(double a=0.0, double b=0.0):
        re(a), im(b) { } ~Complex() { }
    void display();
    double real() { return re; }
    double img() { return im; }
    double set_real(double r) { re = r; }
    double set_img(double i) { im = i; }
} ;
void Complex::display() {
    cout << re << " +j " << im << endl;
}
```

```
Complex operator+(Complex &t1, Complex &t2) {
    Complex sum;
    sum.set_real(t1.real() + t2.real());
    sum.set_img(t1.img() + t2.img());
    return sum;
}
int main() {
    Complex c1(4.5, 25.25), c2(8.3, 10.25), c3;
    cout << "1st complex No:"; c1.display();
    cout << "2nd complex No:"; c2.display();
    c3 = c1 + c2; // Overload operator +
    cout << "Sum = "; c3.display();
}
```


- **Output**:

```
1st complex No: 4.5 +j 25.25
2nd complex No: 8.3 +j 10.25
Sum = 12.8 +j 35.5
```

- Accessing private data members inside operator functions is clumsy
- Critical data members need to be exposed (get/set) violating encapsulation
- **Solution**: Member operator function or `friend` operator function

Using Member Function

Program 18.03: Using Member Function

```
#include <iostream>
using namespace std;
class Complex { // Private data members
    double re, im;
public:
    Complex(double a=0.0, double b=0.0):
        re(a), im(b) { } ~Complex() { }
    void display();
    Complex operator+(const Complex &c) {
        Complex r;
        r.re = re + c.re;
        r.im = im + c.im;
        return r;
    }
} ;
```

```
void Complex::display() {
    cout << re;
    cout << " +j " << im << endl;
}
int main() {
    Complex c1(4.5, 25.25), c2(8.3, 10.25), c3;
    cout << "1st complex No:";
    c1.display();
    cout << "2nd complex No:";
    c2.display();
    c3 = c1 + c2; // Overloaded operator +
    cout << "Sum = ";
    c3.display();
    return 0;
}
```


- **Output**:

```
1st complex No: 4.5 +j 25.25
2nd complex No: 8.3 +j 10.25
Sum = 12.8 +j 35.5
```

- Performing `c1 + c2` is equivalent to `c1.operator+(c2)`
- `c1` invokes the `operator+` function and `c2` is passed as an argument
- Similarly we can implement all binary operators (`%`, `-`, `*`, etc..)
- **Note:** No need of two arguments in overloading

Program 14.14: Overloading operator=: RECAP (Module 14)


```
#include <iostream>
#include <cstdlib>
#include <cstring>
using namespace std;
class String { public: char *str_; size_t len_;
    String(char *s) : str_(strdup(s)), len_(strlen(str_)) { }        // ctor
    String(const String& s) : str_(strdup(s.str_)), len_(s.len_) { } // cctor
    ~String() { free(str_); }                                        // dtor
     String& operator=(const String& s) {
        if (this != &s) { free(str_); str_ = strdup(s.str_); len_ = s.len_; }
        return *this;
    }
    void print() { cout << "(" << str_ << ": " << len_ << ")" << endl; }
};
int main() { String s1 = "Football", s2 = "Cricket";
    s1.print(); s2.print();
    s1 = s1; s1.print();
}
(Football: 8)
(Cricket: 7)
(Football: 8)
```

- Check for self-copy `(this != &s)`
- In case of self-copy, do nothing

Notes on Overloading operator=: RECAP (Module 14)

- Overloaded operator= may choose between *Deep* and *Shallow Copy* for Pointer Members
  - *Deep copy* allocates new space for the contents and copies the pointed data
  - *Shallow copy* merely copies the pointer value – hence, the new copy and the original pointer continue to point to the same data
- If operator= is not overloaded by the user, compiler provides a free one.
- Free operator= can makes only a shallow copy
- If the constructor uses operator new, operator= should be overloaded
- If there is a need to define a copy constructor then operator= must be overloaded and vice-versa

Program 18.04: Overloading Unary Operators

```
#include <iostream>
using namespace std;

class MyClass { int data; public:
    MyClass(int d): data(d) { }

    MyClass& operator++()   { // Pre-increment:
        ++data;               // Operate and return the operated object
        return *this;
    }
    MyClass operator++(int) { // Post-Increment:
        MyClass t(data);      // Return the (copy of) object; operate the object
        ++data;
        return t;
    }
    void disp() { cout << "Data = " << data << endl; }
};
int main() {
    MyClass obj1(8); obj1.disp();
    MyClass obj2 = obj1++; obj2.disp(); obj1.disp();

    obj2 = ++obj1;
    obj2.disp(); obj1.disp();
}
```

- Output

Data = 8
Data = 8
Data = 9
Data = 10
Data = 10

- The **pre-operator** should first perform the operation (increment / decrement / other) and then return the object. Hence its return type should be **MyClass&** and it should return ***this;**

- The **post-operator** should perform the operation (increment / decrement / other) after it returns the original value. Hence it should copy the original object in a temporary **MyClass t;** and then **return t;**. Its return type should be **MyClass** - by value

Program 18.05: Overloading Unary Operators: Pre-increment & Post Increment

```
#include <iostream>
using namespace std;

class MyClass { int data;
public:
    MyClass(int d) : data(d) { }

    MyClass& operator++()    { // Pre-Operator
        data *= 2;
        return *this;
    }
    MyClass operator++(int) { // Post-Operator
        MyClass t(data);
        data /= 3;
        return t;
    }
    void disp() { cout << "Data = " << data << endl; }
};
int main() {
    MyClass obj1(12); obj1.disp();
    MyClass obj2 = obj1++; obj2.disp(); obj1.disp();

    obj2 = ++obj1;
    obj2.disp(); obj1.disp();
}
```

- Output

Data = 12
Data = 12
Data = 4
Data = 8
Data = 8

- The **pre-operator** and the **post-operator** need not merely increment / decrement
- They may be used for any other computation as this example shows
- However, it is a good design practice to keep close to the native semantics of the operator

Module Summary

- Introduced operator overloading for user-defined types
- Illustrated methods of overloading operators using global functions and member functions
- Outlined semantics for overloading binary and unary operators