Queens College, CUNY, Department of Computer Science

Object Oriented Programming in C++

CSCI 211 / 611

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Operator overloading

- In this lecture we shall learn about **operator overloading.**
- We shall also learn about **operators as class methods.**

Class `Point1`: review for later use

- Recall the class `Point1`, which we have used before.

```
class Point1 {
public:
  // public methods
  void set(const double &a, const double &b)
  {
    x = a;
    y = b;
  }

  const double& getx() const { return x; }
  const double& gety() const { return y; }

  void print() const
  {
    cout << "print x,y    " << x << "    " << y << endl;
  }

private:
  // data
  double x, y;
};
```

1 Function overloading

- Let us write functions to add and subtract two `Point1` objects.

  1. With an obvious notation, the data values in the sum are $(x_1 + x_2, y_1 + y_2)$.
  2. Similarly, the data values in the difference are $(x_1 - x_2, y_1 - y_2)$.
  3. The C++ code for the functions `P1plus` and `P1minus` is given below.

```
Point1 P1plus(const Point1 &u, const Point1 &v)  // function
{
  double xsum = u.getx() + v.getx();             // accessor methods
  double ysum = u.gety() + v.gety();
  Point1 p;
  p.set(xsum, ysum);                             // set the sum
  return p;
}

Point1 P1minus(const Point1 &u, const Point1 &v) // operator
{
  double xdiff = u.getx() - v.getx();            // accessor methods
  double ydiff = u.gety() - v.gety();
  Point1 p;
  p.set(xdiff, ydiff);                           // set the difference
  return p;
}
```

1.1 Main program

- Here is a working C++ program to instantiate `Point1` objects and call the above functions.

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

class Point1 {
 // etc
};

// functions P1plus, P1minus

int main()
{
  double c1 = 2.0;
  double c2 = 3.0;
  Point1 p1, p2, p3;
  p1.set(4.4, 3.3);
  p2.set(2.2, 1.1);
  p3.set(0.4, 0.5);

  Point1 pa = P1plus(p1, p2);              // add
  Point1 pb = P1minus(p1, p2);             // subtract
  pa.print();
  pb.print();

  Point1 p123a = P1plus(P1plus(p1, p2), p3);  // (p1+p2) + p3
  Point1 p123b = P1plus(p1, P1plus(p2, p3));  // p1 + (p2+p3)
  p123a.print();
  p123b.print();

  return 0;
}
```

- ***The most important feature of the above program is that it is clumsy.***
- The expressions to add three objects `p1+p2+p3` are particularly ugly.

```
P1plus(P1plus(p1, p2), p3);       // (p1 + p2) + p3
P1plus(p1, P1plus(p2, p3));       // p1 + (p2 + p3)
```

- **Although it works, it is a bad software design.**
- **There is a better way.**

2 Operator overloading, part 1

- Note that the above functions perform the math operations + and −.
- It would be much nicer if we could write code like this:

```
Point1 pa = p1 + p2;
Point1 pb = p2 - p1;
```

- It would also be good to be able to multiply a `Point1` object by a `double`.

```
Point1 pc = c1 * p1;
Point1 pd = p2 * c2;
```

- In this context, there are two different multiplication operations:
  1. `double` times `Point1`.
  2. `Point1` times `double`.
  3. To the compiler, these are distinct operations because the operands are different.
  4. The compiler does not automatically know they are equal.
- **C++ has a way to do write such operators.**
- **As well as writing functions, C++ permits us to write operators.**
- Writing code to create our own definitions of operators is called **operator overloading.**
  1. We can also overload the division operator /.
  2. We can overload other mathematical operators such as `++` and `--`.
  3. We can also overload Boolean operators such as `>`, `>=`, `<`, `<=`, `||` and `&&`.
  4. We can also overload the left and right shift operators `<<` and `>>`.
- **The widely used expression "`cout << (something) << endl;`" is an example of the overloading of the `<<` operator.**
- **However, we cannot overload the dot "." or the arrow "->" operators.**

3 Operator overloading, part 2

- Here is the C++ code for the operators $+$, $-$ and two versions of $*$.
- **They are all examples of operator overloading.**
  1. The first two cases overload the $+$ and $-$ operators, respectively.
  2. They tell the compiler how to add and subtract two `Point1` objects.
- The third and fourth cases overload the $*$ operator in two different ways.
  1. The first overload of $*$ tells the compiler how to multiply `double` and `Point1`.
  2. The second overload of $*$ tells the compiler how to multiply `Point1` and `double`.
- ***Don't panic.***
- Before we rush too fast, in the next section(s) we shall learn step by step how to write C++ code to overload operators.

```
Point1 operator+ (const Point1 &u, const Point1 &v)  // operator
{
  double xsum = u.getx() + v.getx();                 // accessor methods
  double ysum = u.gety() + v.gety();
  Point1 p;
  p.set(xsum, ysum);
  return p;
}

Point1 operator- (const Point1 &u, const Point1 &v)  // operator
{
  double xdiff = u.getx() - v.getx();
  double ydiff = u.gety() - v.gety();
  Point1 p;
  p.set(xdiff, ydiff);
  return p;
}

Point1 operator* (double c, const Point1 &u)         // operator
{
  double x = u.getx() * c;
  double y = u.gety() * c;
  Point1 p;
  p.set(x, y);
  return p;
}

Point1 operator* (const Point1 &u, double c)         // operator
{ return (c*u); }
```

4 Operator overloading, part 3

- Let us learn step by step how to write C++ code to overload operators.
- Recall the overload of the assignment `operator =`.
- Instead of a function name, we write the keyword "`operator`" and the symbol for the operator.
- Hence we write `operator+` for addition.
- After that we write the operator signature. This is reasonably obvious.
- The input arguments of an operator are called its **operands.**
- **However, there is an obvious difference between operands and function inputs.**
  1. Again recall the assignment `operator =`.
  2. In programming statements, the two operands are written on the left and right sides and the operator appears in the middle.
  3. Hence we write expressions of the form $p_1 + p_2$ or $p_1 - p_2$, etc.
  4. **The operator is written between the operands.**
  5. The operator + acts on the operands on its left and its right.
- Finally there is the return type. For the operator +, this is obviously a `Point1` object.
- ***Is it obvious?***
  1. The operator + is one of the most heavily overloaded operators.
  2. We make use of the overloading all the time without even thinking.
  3. *But what are its operands and what is its return type in each case?*

left operand	right operand	return type
int	int	int
int	double	double
double	int	double
double	double	double

  4. *The C++ language must overload every other case, for* `char`, `long`, *etc.*
- What is the return type if we attempt to add a `double` and a `string`? This operation is not supported by the C++ language.
- ***So . . . the correct answer is that the return type is not obvious.***
- *Can the return type be* `void`*?* Yes. (Try it.) But I have no idea what an operator with a `void` return type would do.

5 Operator precedence

- Consider how we would write code to evaluate the expression

$$p = p_1 + p_2\, c_2\,.$$

- Using the overloaded operators, the code would be written in the following way.

```
p = p1 + p2*c2;
```

- *Is this really true? Why?*

  1. Recall that `Point1` is a user-defined class.
  2. We overloaded the operators $+$, $-$ and $*$ to accepts operands of the class `Point1`.
  3. *But we did not say what to do if expressions involving addition and multiplication are mixed.*
  4. **The compiler implements the rules of operator precedence automatically.**
  5. *This is a truly elegant feature of operator overloading.*

- We can write clean expressions such as

```
Point1 pe = p1 + p2 + p3;
Point1 pf = c1 * p1 * c2;
Point1 pg = p1 + p2*c2;
Point1 ph = c1*(p1 + p2*c2);
```

- *The compiler implements all the rules of operator precedence automatically for us.*
- **All of the above expressions will be evaluated correctly.**

6 Unary operators

- The operators $+$, $-$, $*$ and $/$ (which we did not overload) all have two operands.
- They are called **binary operators.**
- A **unary operator** has only one argument.
- Actually the operator $-$ is both a unary and a binary operator.
- We do not normally think of the expression "$-p$" as an operator, but it is:

$$p_1 = -p_2 \, .$$

- The code to overload "$-$" as a unary operator is as follows:

```
Point1 operator- (const Point1 &u)                    // unary operator
{
  double xneg = -u.getx();
  double yneg = -u.gety();
  Point1 p;
  p.set(xneg, yneg);
  return p;
}
```

- There are also other unary operators.

7 Operator overloading, example program

- Here is a working C++ program employing operator overloading and `Point1` objects.
- I have skipped "`pi`" for obvious reasons.

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

class Point1 {
 // etc
};

// code for operator overloads

int main()
{
  double c1 = 2.0;
  double c2 = 3.0;
  Point1 p1, p2, p3;
  p1.set(4.4, 3.3);
  p2.set(2.2, 1.1);
  p3.set(0.4, 0.5);

  Point1 pa = p1 + p2;              // operator +
  Point1 pb = p1 - p2;              // operator -
  Point1 pc = c1 * p1;              // operator (double * Point1)
  Point1 pd = p2 * c2;              // operator (Point1 * double)
  Point1 pe = p1 + p2 + p3;
  Point1 pf = c1 * p1 * c2;
  Point1 pg = p1 + p2*c2;
  Point1 ph = c1*(p1 + p2*c2);
  Point1 pj = -p1;

  pa.print();
  pb.print();
  pc.print();
  pd.print();
  pe.print();
  pf.print();
  pg.print();
  ph.print();
  pj.print();
  return 0;
}
```

8 Operators as class methods

- **Operators can be written as class methods.**
- Let us declare a class `Point1op`, the same as `Point1` but with operators written as class methods.
- The binary operators $+$, $-$ and *one of* $*$ have been declared as class methods.

```
class Point1op {                                    // operators as class methods
public:
  Point1op operator+ (const Point1op & v)  const;  // "this object" + v
  Point1op operator- (const Point1op & v)  const;  // "this object" - v
  Point1op operator* (double d) const;             // "this object" * d
  Point1op operator- () const;                     // unary minus no arguments

  // etc ... rest of class declaration
};
```

- The signature of the binary operators have only one argument.
- The left operand is "this object" (of the method).

```
Point1op operator+ (const Point1op & v)  const  // "this object" + v
{
  Point1op p;
  p.set(x + v.x, y + v.y);
  return p;
}
Point1op operator- (const Point1op & v)  const  // "this object" - v
{
  Point1op p;
  p.set(x - v.x, y - v.y);
  return p;
}
```

- Unlike the previous versions, the above code does not require the use of the accessor methods `getx` and `gety`.
- We are "inside the class" therefore we have access to the values of x, y, `v.x` and `v.y` directly.
- **The operators are tagged `const`, no less.**
- Unlike the assignment `operator=`, the operators $+$ and $-$ do not change "this" object.
- They create a new object internally and return it as the return value.
- Hence the operators can be tagged as `const`.

- **See next page(s).**

- The signature of the unary operator has no arguments (the operand is "this object").

```
Point1op operator- () const                // unary minus, no arguments
{
  Point1op p;
  p.set(-x, -y);
  return p;
}
```

- The operator returns an object with the negated values $(-x, -y)$ of "this" object.
- **The operator is also tagged `const`.**
- Writing `operator*` as a class method presents a difficulty.
- The left operand is "this object" **hence only the operator "`(object * double)`" can be declared as a class method.**

```
Point1op operator* (double d) const          // "this object" * d
{
  Point1op p;
  p.set(x*d, y*d);
  return p;
}
```

- **The operator is also tagged `const`.**
- The operator "`(double * object)`" must be written outside the class, as shown previously.
- Alternatively, we can call the class method, as shown below.

```
Point1op operator* (double c, const Point1op &p)       // operator "double * object"
{
  return (p*c);                                        // call the class method "object *
}
```

- The complete class declaration for `Point1op` is given below.
- Also the external function for operator $*$.
- A working main program is also displayed.

```
class Point1op {
public:
  void set(const double &a, const double &b)
  {
    x = a;
    y = b;
  }

  const double& getx() const { return x; }
  const double& gety() const { return y; }

  void print() const
  {  cout << "print x,y    " << x << "    " << y << endl;  }

  Point1op operator+ (const Point1op & v)  const  // "this object" + v
  {
    Point1op p;
    p.set(x + v.x, y + v.y);
    return p;
  }
  Point1op operator- (const Point1op & v)  const  // "this object" - v
  {
    Point1op p;
    p.set(x - v.x, y - v.y);
    return p;
  }
  Point1op operator- () const              // unary minus no arguments
  {
    Point1op p;
    p.set(-x, -y);
    return p;
  }
  Point1op operator* (double d) const      // "this object" * d
  {
    Point1op p;
    p.set(x*d, y*d);
    return p;
  }

private:
  double x, y;
};

Point1op operator* (double c, const Point1op &p) // double * Point1op
{  return (p*c); }
```

9 Operators as class methods, example program

- The program below looks basically the same as the program in Sec. 7.
- It does not really matter if the operators are written as class methods or not.
- Some operators (such as the assignment `operator=`) *must* be written as class methods.

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

class Point1op {
 // etc
};

// external operator*

int main()
{
  double c1 = 2.0;
  double c2 = 3.0;
  Point1op p1, p2, p3;
  p1.set(4.4, 3.3);
  p2.set(2.2, 1.1);
  p3.set(0.4, 0.5);

  Point1op pa = p1 + p2;              // operator +
  Point1op pb = p1 - p2;              // operator -
  Point1op pc = c1 * p1;              // operator (double * Point1op)
  Point1op pd = p2 * c2;              // operator (Point1op * double)
  Point1op pe = p1 + p2 + p3;
  Point1op pf = c1 * p1 * c2;
  Point1op pg = p1 + p2*c2;
  Point1op ph = c1*(p1 + p2*c2);
  Point1op pj = -p1;

  pa.print();
  pb.print();
  pc.print();
  pd.print();
  pe.print();
  pf.print();
  pg.print();
  ph.print();
  pj.print();
  return 0;
```

```
}
```

10 Summary

- Many operators can be overloaded to operate on user-defined classes.
- The list includes standard mathematical operators such as $+$, $-$, $*$ and $/$.
- The list also includes comparison operators such as $==$, $<$, $\leq$, $>$ and $\geq$, etc., which return Boolean true/false values.
- The compiler automatically implements the rules of **operator precedence** for the operators.
- Some operators such as the dot "$\cdot$" and arrow "`->`" operators cannot be overloaded.
- **Note: We cannot overload operators to act on primitive data types.**
  1. For example, we cannot overload operator $+$ for (`double` and `int`).
  2. We can overload operator $+$ if one of the operands is an object of a user-defined class.
  3. We can overload operator $+$ for (`object` and `int`) or (`double` and `object`), etc.
- The inputs of an operator are called its **operands.**
  1. Operators with two operands are called **binary operators.**
  2. Operators with one operand are called **unary operators**, e.g. unary minus.
- Overloaded operators can be written as (i) functions (i.e. outside a class) or (i) class methods.
  1. If an operator is written as a class method, the "this object" is the left operand.
  2. Some operators, such as the assignment `operator=`, *must* be written as class methods.
  3. Some operators, such as the assignment `operator=`, modify the "this object" therefore they are not `const`.
  4. Other operators do not modify the "this object" therefore they can be tagged as `const`.
- Operators can have many return types.
  1. Comparison operators such as $==$ or $!=$, etc. return a Boolean value.
  2. Operators such as $+$, $-$, $*$ and $/$ typically return an object.
  3. The assignment `operator=` returns a **reference to an object.**
  4. It is also possible for an operator to return a `const` object or reference.
  5. *It is also possible for an operator to return a pointer or an array.*
  6. It is also possible for the return type of an operator to be `void`.
  7. **We are free to choose the return type of an overloaded operator.**