Topic 3
C++ Review Part III: Overloading and Polymorphism

資料結構與程式設計

Data Structure and Programming

10.02.2019

Sharing in the code…

- Remember:

  Many constructs (in C++) are to promote **sharing** in the code.

  1. Pointer: share the same data location (by different variables)
  2. Reference: an alias to an existing variable (usually in different scopes)
  3. Function: share the common codes
  4. Class: data with the same attributes and definition (as data type)

Sharing in the code…

- And we will learn…
  5. Inherited class: different but similar classes sharing the common data members or member functions
  6. Function overloading: same function name, diff arguments
  7. Operator overloading: redefine the C++ operators for user-defined data type (class)
  8. Template class: same storage method, diff data types
  9. Template function: same algorithm flow, diff data types
  10. Functional object: same algorithm flow, diff argument types

Key Concept #1: “Has a” vs. “Is a”

- class Car {
    Engine _eng;
  };
  ➔ Class Car “has a” data member of type “Engine”

- class Dog : public Animal {
  …
  };
  ➔ Class Dog “is a” inherited type of “Animal”

Key Concept #2: Inheritance to share common data and methods

```
◆ class Base {
   public:
     <public data or methods>
   protected:  // public to Derived classes
               // private to others
     <shared data or methods>
   private:    // Base's private only
     <private data or methods>
  };
  class Derived : public Base {
   public:
     <specific data or methods>
   private:
     <specific data or methods>
  };
```


Inheritance to share common data and methods

```
class Car
{
 public:
   Car(){}
   ~Car(){}
   void drive(){}
 protected:
   Engine  _eng;
   short   _year;
   short   _mileage;
};
```

```
class Bus:public Car
{
 public:
   Bus(){}
   ~Bus(){}
 private:
   short   _capacity;
};
Class Truck:public Car
{
 public:
   Truck(){}
   ~Truck(){}
 private:
   short   _weight;
};
```

"protected" vs. "private" access specifiers

- protected:
  - To allow member functions of the derived classes to directly access the base class' data members and member functions
  - To shield other classes from directly accessing
- private:
  - Member functions of the derived classes cannot directly access the base class' private components
  - However, derived classes still inherit the private data members (Remember: "is a")
    - To access them, create protected or public functions in base class
- Note: "friend" specification is NOT inherited

Key Concept #3: Inheritance to specialize distinct methods with the same function name

```
class Shape {
 public:        virtual void draw() = 0;
 protected:     double  _centerCoord;
};
class Square : public Shape {
 public:        void draw();
 private:       double  _edgeLength;
};
class Circle: public Shape {
 public:        void draw();
 private:       double  _radiusLength;
};
```

➔ In C style, people use "switch" ➔ NOT GOOD

Key Concept #4: Polymorphism

- [Recall] Using inherited classes to ---
  - Share common data and methods
    - Put data/functions in base class
  - Specialize distinct methods with the same function name
    - Overloading base class' virtual function
- Polymorphism
  - One entity, multiple faces
  - One action, multiple entities
  - One algorithm, multiple scenarios
  - One interface, multiple instantiations

Practice #1

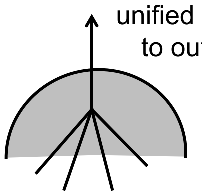
- Define a base `class Base` and its derived `class Derived`
  - For `class Base`, define two public functions:
    - `virtual void f();  void g();`
  - For `class Derived`, define two public functions:
    - `void f();  void g();`
  - In the above functions, print out message showing that the function is called (e.g. "Base::f() is called").
- In main, instantiate two objects "`Base b`" and "`Derived d`". Use them to call `f()` and `g()`
  - Which functions are called?
  - What does "`virtual`" keyword do in this case? What if we do NOT declare "`virtual`"?
  - What if we do NOT declare inheritance?

Is this virtual function useful?

<pre>class Base {
 public:
   virtual void f();
   void g();
};
class Derived: public Base
{
 public:
   void f();
   void g();
};
int main()
{
   Base b; b.f(); b.g();
   Derived d; d.f(); d.g();
}</pre>
	➔ Which f() and g() are called?
	Base::f()
	Base::g()
	Derived::f()
	Derived::g()
	
	➔ What does "virtual" keyword do in this case? What if we DO NOT declare "virtual" for f()?
	
	➔ What's the difference if we DO NOT declare Derived as a derived class of Base?

Key Concept #5: Virtual function is useful ONLY with polymorphism

- Polymorphism occurs when a derived object invokes a virtual function through a base-class pointer or reference
  - C++ dynamically chooses the correct function for the class from which the object was instantiated
- Common usage:
  - Base *p = new Derived;
    p->virtualFunction();
  - Derived d;
    f(d);
    f(Base &r) {
        r.virtualFunction();
    }



Practice #2

- Define a base `class Base` and its derived `class Derived`
  - For `class Base`, define three public functions:
    - `virtual void f(); void g(); virtual void h();`
  - For `class Derived`, define two public functions:
    - `void f();  void g();`
  - In the above functions, print out message showing that the function is called (e.g. "Base::f() is called").
- In main, instantiate three objects "`Base *p = new Derived`", "`Base *q = new Base`" and "`Derived *r = new Derived`". Use them to call `f()`, `g()` and `h()`
  - Is it OK NOT to define "`Derived::h()`"?
  - Which functions are called?

Virtual Functions

```
class Base {
 public:
   virtual void f() {}
   void g() {}
   virtual void h() {}
};
class Derived: public Base
{
 public:
   void f() {}
   void g() {}
};
int main()
{
   Base* p = new Derived;
   p->f(); p->g(); p->h();
```

```
   Base* q = new Base;
   q->f(); q->g(); q->h();

   Derived* r = new Derived;
   r->f(); r->g(); r->h();
}
```

➔ **Any compilation error?**
➔ **Which f(), g(), h() are called?**

== p ==
Derived::f()
Base::g()
Base::h()
== q ==
Base::f()
Base::g()
Base::h()
== r ==
Derived::f()
Derived::g()
Base::h()

Key Concept #6: Polymorphism for dynamic type specification

- Analogy:
  - The size of a dynamic array is undefined.
    It is determined during execution.

  ➔
```
int  *arr = 0;
…  // size is determined
arr = new int[size];
```

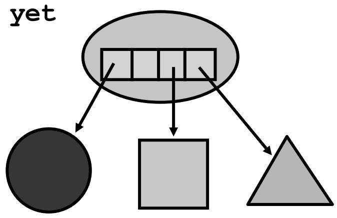
- When the type of a variable is not determined before execution, but its category is clearly defined…

  ➔ Category: base class; type: inherited class

  ➔
```
Category *p;
…
p = new MyType;
```


[NOTE] We can use "base class pointer" when the type of the derived class is not determined in the beginning

```
class Node {
   Array<Node*>  _children;
public:
   void addChild(Node* c) {_children.push_back(c); }
};
class Circle: public Node {...};
class Square: public Node {...};
-------------------------------------------
Node  *o1, *o2; // type is not yet
...             // determined
o1 = new Circle;
o2 = new Square;
n->addChild(o1);// Let n be
n->addChild(o2);// the parent
```



Key Concept #7: Virtual function makes polymorphism meaningful

- Use base class pointer or reference as the interface.
  Pass inherited class pointer or object for different application scenarios.
- [Example] HW #3's command registration

```
class CmdExec {
public:
   virtual CmdExecStatus exec(const string&) = 0;
   virtual void usage(ostream&) const = 0;
   virtual void help() const = 0;
};
class HelpCmd : public CmdExec {
public:
   CmdExecStatus exec(const string& option);
   void usage(ostream& os) const;
   void help() const;
};
class QuitCmd : public CmdExec { ... };
```


More on HW#3: CmdExec as common interfaces for command-related operations

- Command registration

```
class CmdParser {
   map<const string, CmdExec*>  _cmdMap;
};
int main() {
   if (!initCommonCmd() || !initCalcCmd())...
}
bool initCommonCmd() {
   if (!(cmdMgr->regCmd("Quit", 1, new QuitCmd) &&
         cmdMgr->regCmd("HELp", 3, new HelpCmd)...
}
bool CmdParser::regCmd(..., CmdExec* e) {
   return (_cmdMap.insert
          (CmdRegPair(mandCmd, e))).second;
}
```

More on HW#3: Command Execution

```
int main() {
   while (status != CMD_EXEC_QUIT) {
      status = cmdMgr->execOneCmd();
   }
}
CmdExecStatus
CmdParser::execOneCmd()
{
   readCmd(*dofile);
   // read cmd string from _history.back()
   // retrieve cmd from map<string, CmdExec*>
   CmdExec* e = parseCmd(option);
   return e->exec();
}
```


More on HW #3: CmdClass MACRO

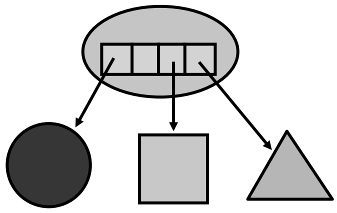
- For each inherited class:

```
#define CmdClass(T)                              \
class T: public CmdExec {                        \
public:                                          \
   T() {}                                        \
   ~T() {}                                       \
   CmdExecStatus exec(const string& option); \
   void usage(ostream& os) const;                \
   void help() const;                            \
}
```

- Implement “exec()”, “usage()” and “help()” functions independently in each package/directory
  ➔ Easy to extend the set of commands

In the previous "Node" example...

- ```
  class Node { virtual void draw() const=0; }
  class Circle: public Node { void draw() const; }
  class Square: public Node { void draw() const; }
  ```
- ```
  void Graph::dfsTraverse() {
     Graph::setGlobalRef();
     dfsTraverse(_root);
  }
  void Graph::dfsTraverse(Node *n) {
     if (n->isGlobalRef()) return;
     n->setGlobalRef();
     for_each_child(c, n)
        dfsTraverse(c);
     n->draw();
  }
  ```



Key Concept #8: Function prototype of virtual function

- Be sure to make the function prototype of the inherited class exactly the same as that of the base class, including "const", etc.
- Once a function is declared `virtual`, it remains `virtual` all the way down the inheritance hierarchy from that point, even if that function is not explicitly declared `virtual` when a class overrides it.
  - But explicitly declare virtual will make the program more readable

Virtual Functions

```
class Animal {
   // no "bark" is defined
};
class Dog: public Animal {
 public:
   virtual void bark();
};
class KDog: public Dog {
 public:
   void bark();
};
class GDog: public KDog {
 public:
   void bark();
};
```

```
int main() {
   Animal *a = new KDog;
   a->bark();

   Dog *b = new KDog;
   b->bark();

   Dog *c = new GDog;
   c->bark();

   Kdog *d = new Gdog;
   d->bark();
}
```

➔ **Any compilation error?**
➔ **Which bark() is called?**

Key Concept #9: Abstract class and pure virtual function

- A class is said "abstract" if we have no intention to create any object out of it.
  - e.g. "Node", "CmdExec" in the previous examples
- A "pure virtual function" is a function defined as "= 0".
- If a class has a pure virtual function, this class becomes "abstract".
  - If patent class has a pure virtual function, it is abstract and we cannot omit the function definition of this pure virtual function in the derived class.
  - We cannot create any object for an abstract class (e.g. Node n; Node *p = new Node;)
  - But polymorphism is OK (e.g. Node *n = new Circle)

Practice #3

- Define a base `class Base` and its derived `class Derived`
  - For `class Base`, define three public functions:
    - `virtual void f(); void g(); virtual void h();`
  - For `class Derived`, define two public functions:
    - `void f();void g();`
  - In the above functions, print out message showing that the function is called (e.g. "Base::f() is called").
- In main, instantiate an object "`Base *p = new Derived`". Use it to call `f()`, `g()` and `h()`
  - Any compilation error?
  - Which ones are called?

Practice #3 (cont'd)

- Follow the modifications below, see if there is any compilation error for each of the steps? Try to read the error message and understand why.
  1. Add one more public function `void h()` for `class Derived` without function body
  2. Make "`Base::h()`" pure virtual
  3. Comment out "`Derived::h()`"
  4. Comment out the call "`p->h()`" in "`main()`"
  5. Uncomment "`Derived::h()`" and write a function body for it; uncomment out the call "`p->h()`";
  6. add a "`Base *q = new Base`" in "`main()`".

Summary #1: Keyword "virtual"

- Explicitly add the keyword "virtual" whenever applicable
  - Only if this function will NOT be made virtual in the future
- The function definition in the inherited class can be omitted if the intention is to call the base-class function
  - But NOT applicable if the function in the base class is pure virtual.

Key Concept #10: Constructors

- As its name suggests, the constructor of the "base" class will be called before that of the inherited class.
  - Both will/must be called.
- Constructor cannot be virtual
  - Doesn't make sense to be virtual.

- What about destructor? Which one will be called first?

Key Concept #11: Virtual Destructor

```
class Base
{
   A  _a;
 public:
   Base(){}
   ~Base(){}
};

class Derived:public Base
{
   B  _b;
 public:
   Derived(){}
   ~Derived(){}
};
```

```
int
main()
{
   Base* p = new Derived;
   Base* q = new Base;
   Derived* r = new Derived;
   ...
   delete p; delete q;
   delete r
}
```

➔ Which constructors / destructors are called?

Base(), Derived; Base(); Base(), Derived()

~Base(); ~Base(); ~Derived(), ~Base()

➔ Why? What's the difference? What's wrong when the derived class' destructor is not called?

Declaring Virtual Destructor

```
class Base
{
   A  _a;
 public:
   Base(){}
   virtual ~Base(){}
};

class Derived:public Base
{
   B  _b;
 public:
   Derived(){}
   ~Derived(){}
};
```

```
int
main()
{
   Base* p = new Derived;
   Base* q = new Base;
   Derived* r = new Derived;
   ...
   delete p; delete q;
   delete r
}
```

➔ Which constrcutors / destructors are called?

Key Concept #12: Calling Base Constructor

```
class Base
{
 public:
   Base(int){}
   virtual ~Base(){}
};

class Derived:public Base
{
 public:
   Derived(int){}
   ~Derived(){}
};
```

```
int
main()
{
   Base *p
     = new Derived(10);
   Base *q = new Base(20);
   ...
   delete p;
   delete q;
}
```

➔Compilation error. Why?

Why compilation error?

◆By default, “Base()” will be called by any “Derived(...)”

```
[Sol #1]
class Base {
 public:
   Base() {}
   Base(int){}
   virtual ~Base(){}
};

class Derived: public
  Base {
 public:
   Derived(int){}
   ~Derived(){}
};
```

➔ But “Base(int)” won’t be called

```
[Sol #2]
class Base {
 public:
   Base(int){}
   virtual ~Base(){}
};


class Derived: public Base {
 public:
   // Explicitly call Base(i)
   Derived(int i):Base(i){}
   ~Derived(){}
};
```

➔ Recommended

Summary #2: Constructor & Destructor

In short, when calling constructor / destructor of the derived class,

make sure the data members in the base and derived class are well taken care of

➔

1. Explicitly calling Base constructor
2. Define "virtual" Base destructor

Key Concept #13: Casting a base class pointer to the derived class

- class Base { };
  class Derived: public Base {
  public: void derivedOnlyMethod() {}
  };
  ======
  Base *p = new Derived();
  p->derivedOnlyMethod();
  ➔ Any problem?
  ➔ Compile error if "f()" is not defined in Base
- When we declare a member function in a derived class, and we use polymorphism to define the variable as a base class pointer
  - How can we call the derived class' member function?
  - Create a (pure) virtual function that does nothing?
    - If so, what about the other derived classes?

  ➔ Leave the member function in derived class only; use "type casting" to cast the pointer from base class to derived class

dynamic_cast<Type>(variable)

- [Note] Use "dynamic_cast" to cast between "base" and "derived" classes

```
class Child : public Parent {
  void childOnlyMethod();
  // no virtual childOnlyMethod() in Parent
  ...
};
// Better make sure, "Parent* p = new Child;"
void f(Parent *p) {
   dynamic_cast<Child *>(p)
          ->childOnlyMethod();
};
```

- [Note] If the underlying object is NOT of the derived type, 0 is assigned; ➔ Used with caution!!

static_cast<Type>(variable)

- [Note] Use "static_cast" to cast between "base" and "derived" classes

```
class Child : public Parent {
  void childOnlyMethod();
  // no virtual childOnlyMethod() in Parent
  ...
};
// Better make sure, "Parent* p = new Child;"
void f(Parent *p) {
   static_cast<Child *>(p)
          ->childOnlyMethod();
};
```

- [Note] No checking between sizes of objects; also use with caution

Key Concept #14: Access specifier in derived classes

- class Derived : [accessSpecifier] Base { ... };
  - private/protected/public
- Data accessibility in derived classes

access specifier \ data in Base	private	protected	public
private	N/A	private	private
protected	N/A	protected	protected
public	N/A	protected	public

- Note: “accessSpecifier” is optional
  - class Derived: Base; ➔ class Derived: private Base;
  - struct Derived: Base; ➔ struct Derived: public Base;

When should we use “struct” in C++?

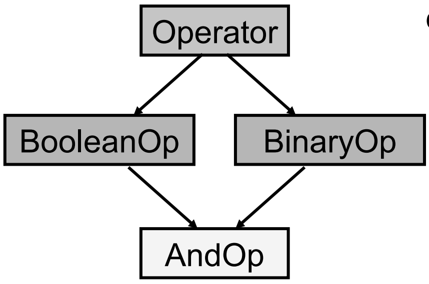
- Since “struct” in C++ is almost the same as “class” --- have data members, member functions, public/private, inheritance, friend… etc. The only difference is that the default in “struct” is public. When should we use “struct” in C++?

  ➔ Some “utility class” should be made available for all applications

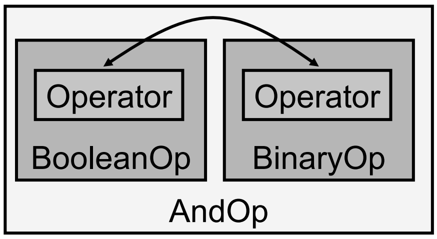
  ➔ e.g. “struct pair”, “struct binary_function” and many others in STL
- If you define a class that is intended to be publicly used by others, make it a “struct”.

Key Concept #15: Multiple Inheritance

- class Operator {};
  class BooleanOp : public Operator {};
  class BinaryOp : public Operator {};
  class AndOp : public BooleanOp, public BinaryOp {};

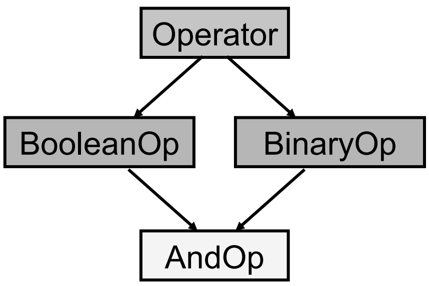


duplicated “Operator” sub-objects

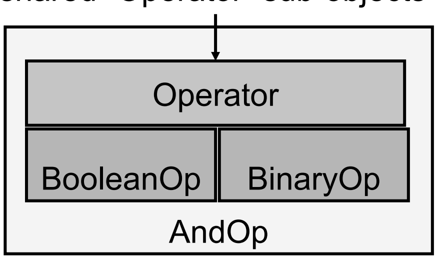


Multiple Inheritance

- class Operator {};
  class BooleanOp : virtual public Operator {};
  class BinaryOp : virtual public Operator {};
  class AndOp : public BooleanOp, public BinaryOp {};



shared “Operator” sub-objects



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  7. Operator overloading: redefine the C++ operators for user-defined data type (class)
  8. Template class: same storage method, diff data types
  9. Template function: same algorithm flow, diff data types
  10. Functional object: same algorithm flow, diff argument types

Key Concept #16: Function Overloading

- Sometimes we want to call the same function with different types/number of parameters, and we don't want to create different function names for them...
  - e.g. // kind of awkward...
    void computeScore(int);
    void computeScore(const Student&);
- Function overloading
  - Same function name, different function arguments (i.e. different signatures)

Key Concept #17: Can't overload a function with different return types

- "Return type" is NOT part of the function signature.
  - e.g.

    bool f() { ... }

    int f() { ... }

    int main() { int i = f(); }

    ➔ Which one is called?

Key Concept #18: Default argument

- You cannot overload a function with and without default argument
  - e.g.

    void f(int i = 0);

    void f(int i);

    ➔ Compile error!! "f(int)" is redefined...
- But this is OK:
  - "void f()" co-exists with "void f(int i = 0)"
  - However, compile error if "f()" is called.
- Default argument can ONLY appear once in the entire program. And it should be declared in the first encounter.
  - Usually the function prototype or inside the class definition
  - Compile error if multiply declared, even with the same value!!

Key Concept #19: Why operator overloading?

- Operator overloads are very useful in making the code more concise (c.f. Function overload)
- Basic concept:

```
MyNumber n1, n2;
n1 = "32hf908abc0";
n2 = f(...);
...
MyNumber n3 = n1 + n2;  // n1.add(n2);
```

1. n1 calls "MyNumber::operator +" with parameter n2
   ➔ return a temporary object, say n4
2. n3 calls "MyNumber::operator =" with parameter n4
   ➔ returned result is stored in n3 itself

Key Concept #20: Pay attention to the function prototypes for operator overloading

```
1.  T& operator = (const T& v);
2.  T& operator [] (size_type i);
3.  const T& operator [] (size_type i) const;
4.  T operator ~ () const;   // also for -, &, |, etc
5.  T& operator ++();        // ++v
6.  T operator ++(int);      // v++
7.  T operator + (const T& v) const;
    // also for -,*,&,etc
8.  T& operator += (const T& v);
    // also for -=,*=,&=,etc
9.  bool operator == (const T& v) const;
    //also for !=, etc
10. friend ostream& operator << (ostream&, const T&);
```

- The operator '()' can also be overloaded and used as "generator"

Return (*this)?

- Note the difference between:
  T operator + (const T& v) const;
  T& operator += (const T& v);
  - Return T vs. T&? const vs. non-const?
- `class T { int_data; … };`
  - ```
    T T::operator + (const T& v) const {
        return T(_data + v._data); }
    ```
  - ```
    T& T::operator += (const T& v) {
        _data += v._data;
        return (*this);
    }
    ```


Practice #4

- Define a `class A` and with data member "`int _d`" and a constructor to initialize this data member (with default = 0).
  - Implement all the overloaded operators in the previous page (maybe except "[]")
  - Play with the combinations of the operators, such as "a + b - c", "a++ + b", "++a * c", "a += b + c"… Check if the behavior matches your expectation.
  - Can you overload operators "()", "{}", "->", "."? Why and why not?

Why const version of "`const T& operator [] (size_type i) const`"?

- Try this:

```
template<class T> class Array {
  public:
     Array(size_t i = 0) { _data = new T[i]; }
     T& operator[] (size_t i) { return _data[i]; }
     const T& operator[] (size_t i) const {
        return _data[i]; }
  private:
     T  *_data;
};
int main() {
   const Array<int> arr(10);  // size = 10
   cout << arr[0] << endl;
   arr[1] = 20;
}
```

➔ **Any compilation error?**

➔ **What if we comment out the const one?**
What if we change it to "T& operator[](…) const"?
Does it make sense?

Practice #5

- Change the previous page's example to:

```
template<class T> class Array {
  public:
     Array(size_t i = 0) { _data = new T[i]; }
     T& operator[] (size_t i) { return _data[i]; }
     const T& operator[] (size_t i) const {
        return _data[i]; }
  private:
     T  *_data;
};
template<class T>
void f(const Array<T>& arr) {
   arr[1] = 20;
   int a = arr[0];
}
int main() {
   Array<int> arr(10);  // size = 10
   f(arr);
}
```

- Compile it and run. Any error?
- Comment out const version of operator []. Compile again. Any error?
- Change the non-const version to "`T& operator[] (size_t i) const…`" and compile again. Any error? If not, does this make sense?

Key Concept #21: More about “()”

- Explicit calling constructor // by class name
  - return A();
  - return B(10, “Ric”);
- Calling overloaded operator () // by object
  - a()
  - a(10, “Ric”)
- Data member initializer // by data member
  - class A {

```
class A {
   B _b;
public:
   A() : _b(10) { ... }
};
```


Key Concept #22: Member or global function?

- e.g. “a + b” can be treated as
  1. Member function : “a.operator +(b)” or
  2. Global function : “::operator +(a, b)”

  ➔ Either one is fine, but...

  ➔ Compile error will arise if both are defined.
- Explicitly calling overloaded operator functions
  - e.g. “a.operator +(b)” is equivalent to “a + b”
  - Or: “::operator +(a, b)”

Key Concept #23: Why "friend"?

- It's common to see "friend" in "operator <<"

```
class A {
   friend ostream& operator <<
   (ostream& os, const A& a);
};
int main() {
   cout << a1 << a2 << endl;
}
```

- "operator <<" here is NOT a member function
  - Can it be a member function?
  - Who calls "cout << a1 << a2"?
  - Is there a "operator << (const A&)" member function for class ostream?
    - Can we overload "ostream::operator <<"?

Global Function: "ostream& operator << (ostream&, const A&)"

- Since "operator << (const A&)" cannot be a member function for class ostream
  - "ostream& operator << (ostream&, const A&)" must be a global function
- "cout << a1"
  - "cout" is an object of class ostream
    - Tied to standard output (screen)
  - How is it called? ::operator << (cout, a1)
- ostream& operator << (ostream& os, const A& a) {
     return (os << a._data);
  }
  - cout << a1 << a2 ➔ cout << a2
- Declaring class A as friend of "operator << (ostream& os, const A& a)" is just for easy data access
  - Can we NOT declare it friend? Why declaring "friend"?
  - ➔ Make it observable in the class definition

Key Concept #24: Syntax and Semantics for Operator Overloading

- There is no restriction on the semantics of the overloaded operators.
  - For example, you can overload an addition operator "+" and define it as performing "subtraction".
  - No compile error/warning.
  - But since it is counter-intuitive, you may introduce some runtime error.
- The syntax of the operators is defined in language parser (compiler). You cannot change it.
  - For example, you cannot do "a ++ b".
- The return type of operators can be arbitrary.
  - However, please make it intuitive.
- The arguments for "()" operator can be arbitrary.

Practice #6

- Define a `class A` and with data member "`int _d`" and a constructor to initialize this data member (with default = 0). Instantiate "`A a1(10), a2(20)`" and call "`a1 + a2`".
  - Overload `operator +` as its member function.
  - Change it to a public function with two `class A` objects as its parameters.
  - What happens if both of the above exist?
- Change the behavior of the "`operator +`" to subtraction. Any compilation error?

Key Concept #25: Return-by-Object or Reference?

- To share the codes in operator overloading implementations, the "return-by-object" version of the operator overloading function usually reuses the "return-by-reference" one.
- e.g.

```
T operator ++(int) {   // i++
   T ret = *this; ++(*this); return ret;
}
T operator + (const T& v) const {
   T ans = *this; ans += v; return ans;
}
```


Example: Random Number Generator

```
class RandomNumGen {
 public:
   RandomNumGen() { srandom(getpid()); }
   RandomNumGen(unsigned seed) { srandom(seed); }
   int operator() (int range) const {
      return int(range * (double(random()) / INT_MAX));
   }
   int operator() (int min, int max) const { ... }
};

main()
{
   RandomNumGen rn;
   ...
   int a = rn(10);  // random number in [0, 9]
   int b = rn(100); // random number in [0, 99]
   int c = rn(10, 100);
}
```

Sharing in the code…

- And we will learn…
  5. Inherited class: different but similar classes sharing the common data members or member functions
  6. Function overloading: same function name, diff arguments
  7. Operator overloading: redefine the C++ operators for user-defined data type (class)
  8. Template class: same storage method, diff data types
  9. Template function: same algorithm flow, diff data types
  10. Functional object: same algorithm flow, diff argument types

Key Concept #26: Template Class

- When the methods of a class can be applied to various data types
  - Specify once, apply to all
  - Container classes

  e.g.

```
template <class T>
class vector {
    ....
};
---------------------
vector<int>            arr;
vector<vector<int> >   arr2D;
```

➔ [note] it's a good practice to make a space between "> >"

➔ [note] "template <class T> is a modifier, not a variable definition, to the class/function in concern. It can be repeated in the same file.

Key Concept #27: Template's Arguments

- Can also contain expression
  - However, the 1st argument must be class name

  e.g.

```
template<class T, int SIZE>
class Buffer
{
   T   _data[SIZE];
};
------------------------------
Buffer<unsigned, 100>  uBuf;
Buffer<MyClass, 1024>  myBuf;
```

➔ **Why not use "#define" or declare it as a data member?**

Key Concept #28: Template Function

- A common method/algorithm that can be applied to various data types

  e.g.

```
template<class T>
void sort(vector<T>&)
{
    ...
}
---------------------
vector<int> arr;
...
sort<int>(arr);
```

Notes about template function

- Template arguments
  - Any of the template arguments can be class type or expression
  ➔ `template <int S> void f() { … while (i < S)… }`
  - The template type symbol(s) can be used in function prototype and/or function body
- When calling template functions, template type symbols can be omitted
  - `template <class T> void f (T a) { ... }`
    `int main() { f(3); f(3.0); }`
- However, if there is(are) "non-type" symbol(s), or ambiguity arises, you need to explicitly specify the template symbol(s)
  - e.g.

```
template <class T> void f() { ... }
int main() {
   f();       // Error, cannot determine T
   f<int>():
}
```


Key Concept #29: Functional Object

- Remember:
  - You can overload the "()" operator for a class
  - e.g.

```
class A {
   bool operator() (int i) const {
      return (_data > i); }
};
```

  ➔ Note: returned type and input parameters may vary
  - What if you pass in such kind of an object to a function?
  - e.g.

```
void f(const Compare& cmp,
       const T& a, const T& b) {
   if (cmp(a, b)) ...
}
```

  ➔ Look like a function pointer?

Functional Object in Polymorphism

- A class/object whose main purpose is to perform a specific function
  - "()" is overloaded
  - Usually passed as reference or pointer to other functions
- Work with class inheritance
  -
```
class Compare {
   virtual bool operator() (int) const = 0; };
class Less : public Compare {
   bool operator() (int) const; };
class Greater : public Compare {
   bool operator() (int) const; };
====================================
void f(const Compare& p);
int main() {
   Less a;  f(a);    // f(a()) ← Error
   f(Greater());     // f(Greater) ← Error
}
```


Practice #7

- Figure out why the following code has compilation errors.
  -
```
#include <algorithm>
#include <iostream>
using namespace std;
struct Compare {
   virtual bool operator() (int, int)
      const = 0; };
struct Less : public Compare {
   bool operator() (int i, int j)
      const { return (i < j); } };
struct Greater : public Compare {
   bool operator() (int i, int j)
      const { return (i > j); } };
void f(const Compare& c) {
   int arr[10] = { 4,2,6,7,1,3,5,9,8,0 };
   ::sort<int*>(arr, arr+10, c);
   for (int i = 0; i < 10; ++i)
      cout << arr[i] << endl;
}
int main() {
   f(Less());
   f(Greater());
}
```

Example of Functional Object Applications

- Graph traveral
  - In a graph data structure, provide a generic traversal function (DFS or BFS).
  - Take a base class functional object as the parameter
    - class DoVertex {
      virtual void operator() (Vertex *) = 0;
      };
  - Define derived classes for intended actions
    - e.g. PrintVertex, Simulate, SetMark, etc

  ➔ Same graph traversal code, different functionalities

(FYI) Functional Object and Algorithm Classes in STL

- Many algorithm and functional object classes in STL
  - for_each, find, copy, sort, swap, search, random_shuffle, power, ...etc
  - unary function, binary function, predicate
  - arithmetic, logic, comparison operations

  ➔ For more information, please refer to: http://www.sgi.com/tech/stl/
  (See: Table of contents)

Summary #3: Template Class/Function vs. Function Overload vs. Functional Object

To maximize code reuse (less duplicated code)

- Template
  - Class template
    - Same storage method, different data types
  - Function template
    - Same algorithm flow, different data types
- Function overloading
  - Same function name, different function arguments
- Functional object
  - Same algorithm flow, different functional methods as "arguments"