Ve 280

Programming and Introductory Data Structures

Container of Pointers; Polymorphic Containers;

Operator Overloading

Outline

- Container of Pointers
- Polymorphic Containers
- Operator Overloading

Review

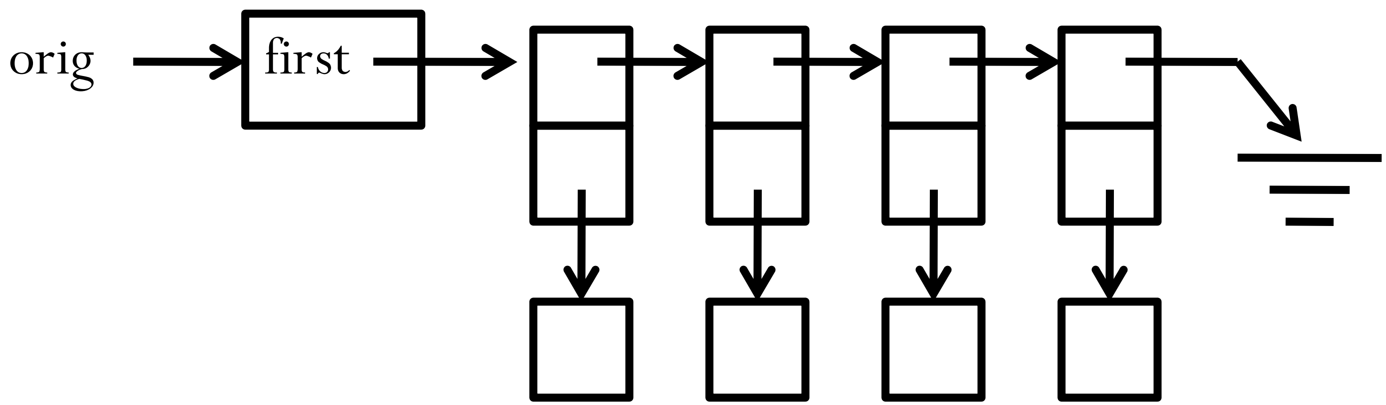
- Container of Pointers
- Subject to bugs. To avoid bugs
  - At-most-once invariant
  - Existence rule
  - Ownership rule
  - Conservation rule
- Due to conservation rule, we should rewrite destructor

Container of Pointers

Copy

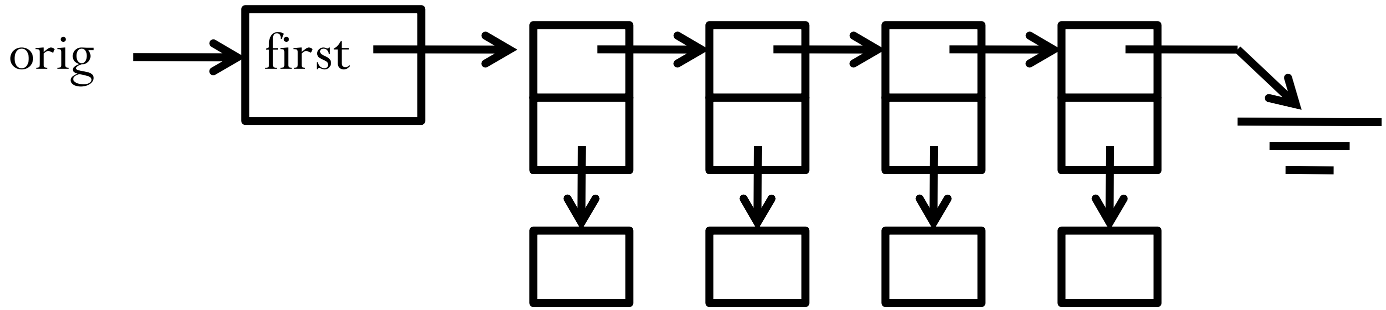
- Copy is also tricky for container of pointers.

- Here is the original singly-linked list of `T*`s :



Container of Pointers

Copy



- Here is the old copy constructor and utility function:

```
template <class T>
List<T>::List(const List &l) {
  first = NULL;
  copyList(l.first);
}
```

Question: Does it violate any invariant or rules (Existence, Ownership, Conservation)? Which? Why?

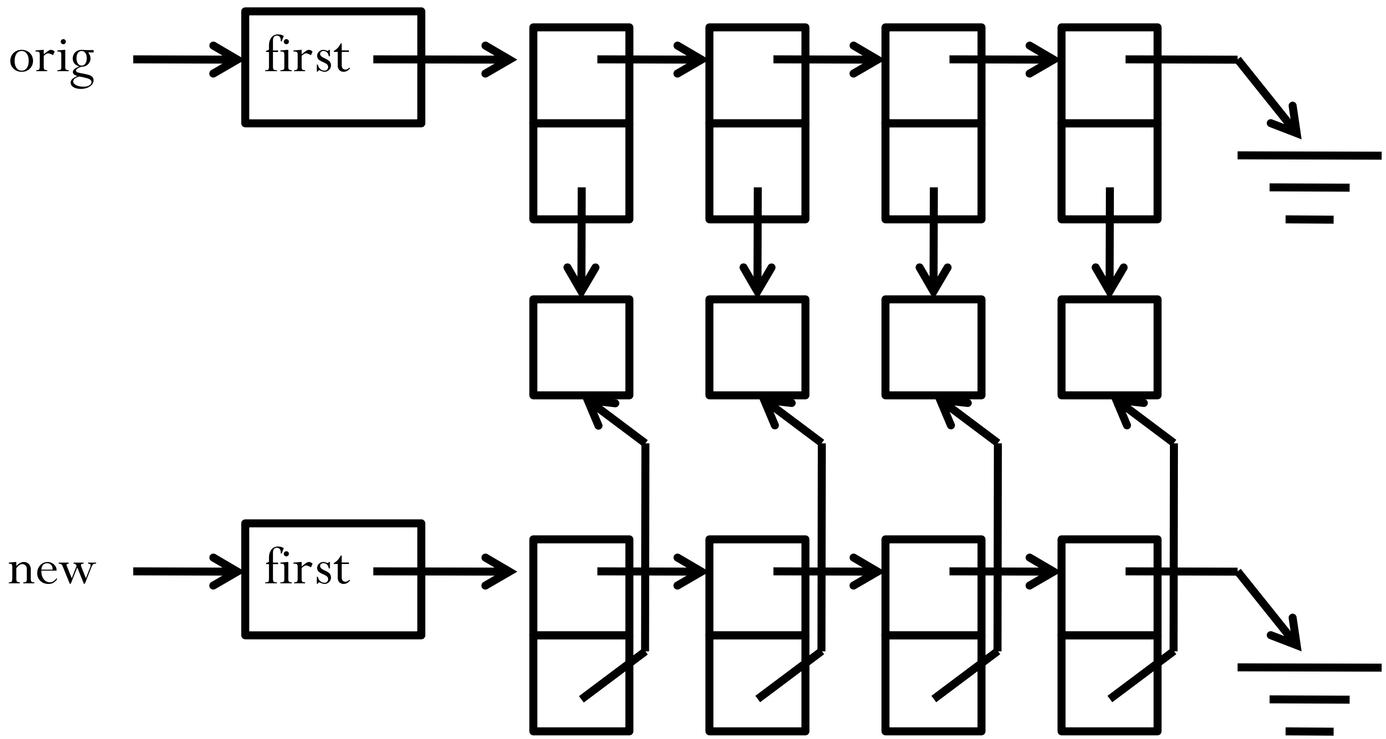
```
template <class T>
void List<T>::copyList(node *list) {
  if(!list) return;
  copyList(list->next);
  insert(list->value);
}
```

T * type

Container of Pointers

Copy

- The list we would end up with is:

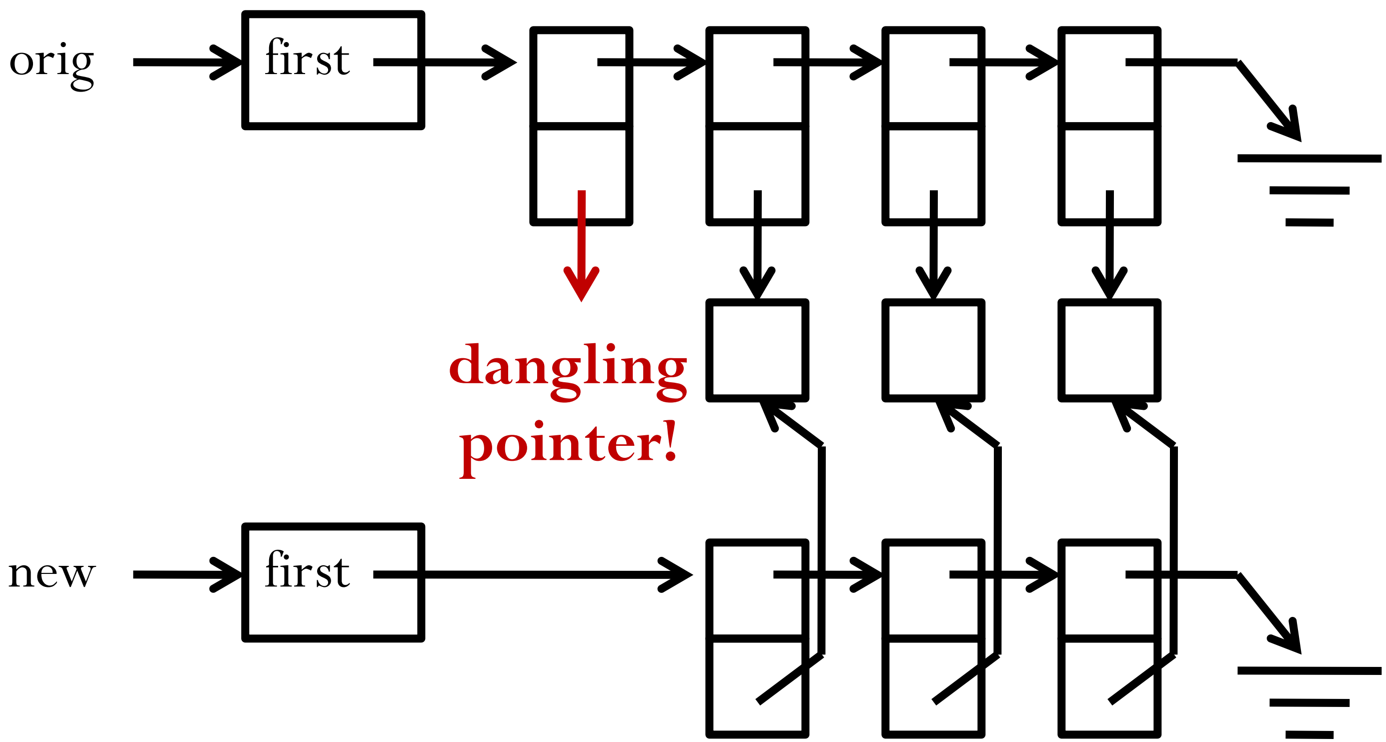


This violates the at-most-once invariant

Container of Pointers

Copy

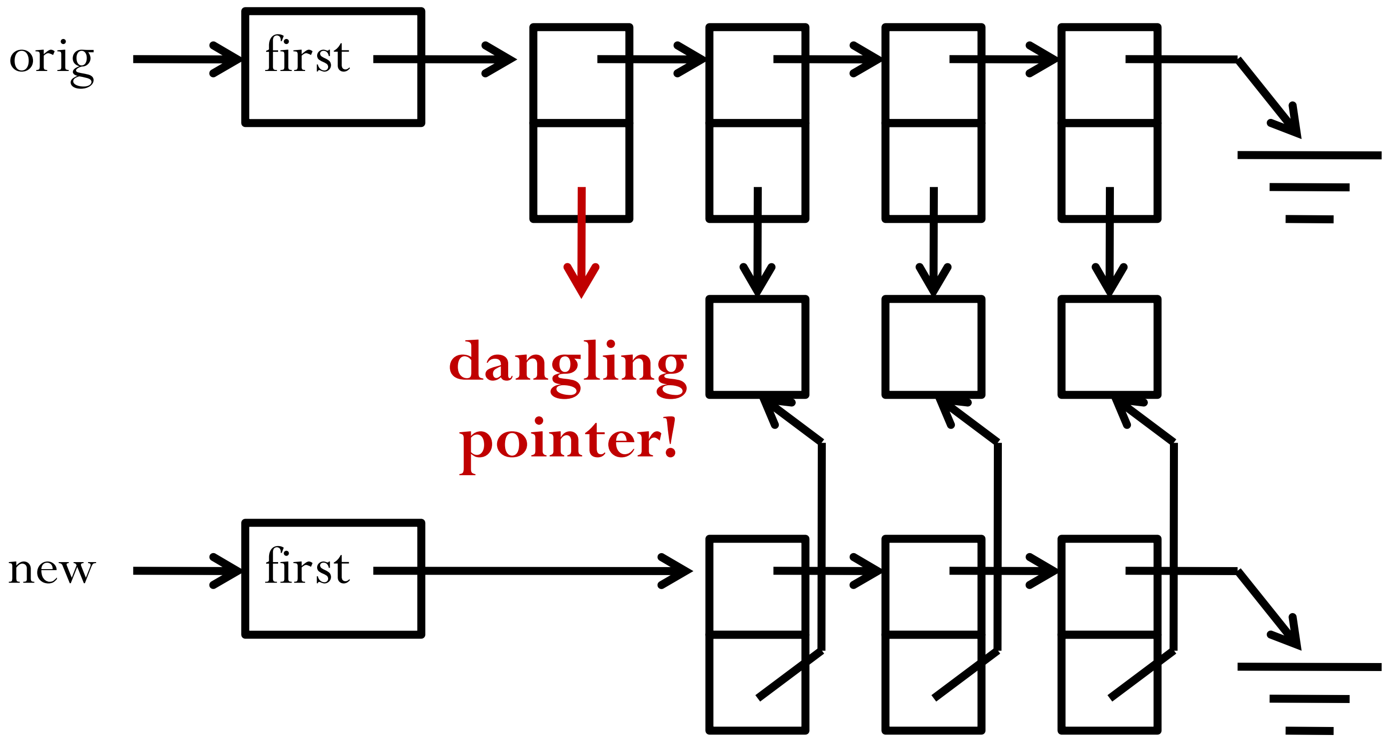
- Now, if we remove the first item of the `new` list, we delete the first node, and return a pointer to the item.
- The client will use the item and delete it (Why?).
- Leaving us with this:



Container of Pointers

Copy

- Clearly, this is not a good thing because we aren't doing a "full" **deep copy**.
- The list nodes are deeply copied, but the `T`s are not since we are copying the pointers, but **not** the objects they point to.



Container of Pointers

Copy

- Fix:

```
template <class T>
void List<T>::copyList(node *list) {
  if (!list) return;
  copyList(list->next);
  T *o = new T(*list->value);
  insert(o);
}
```

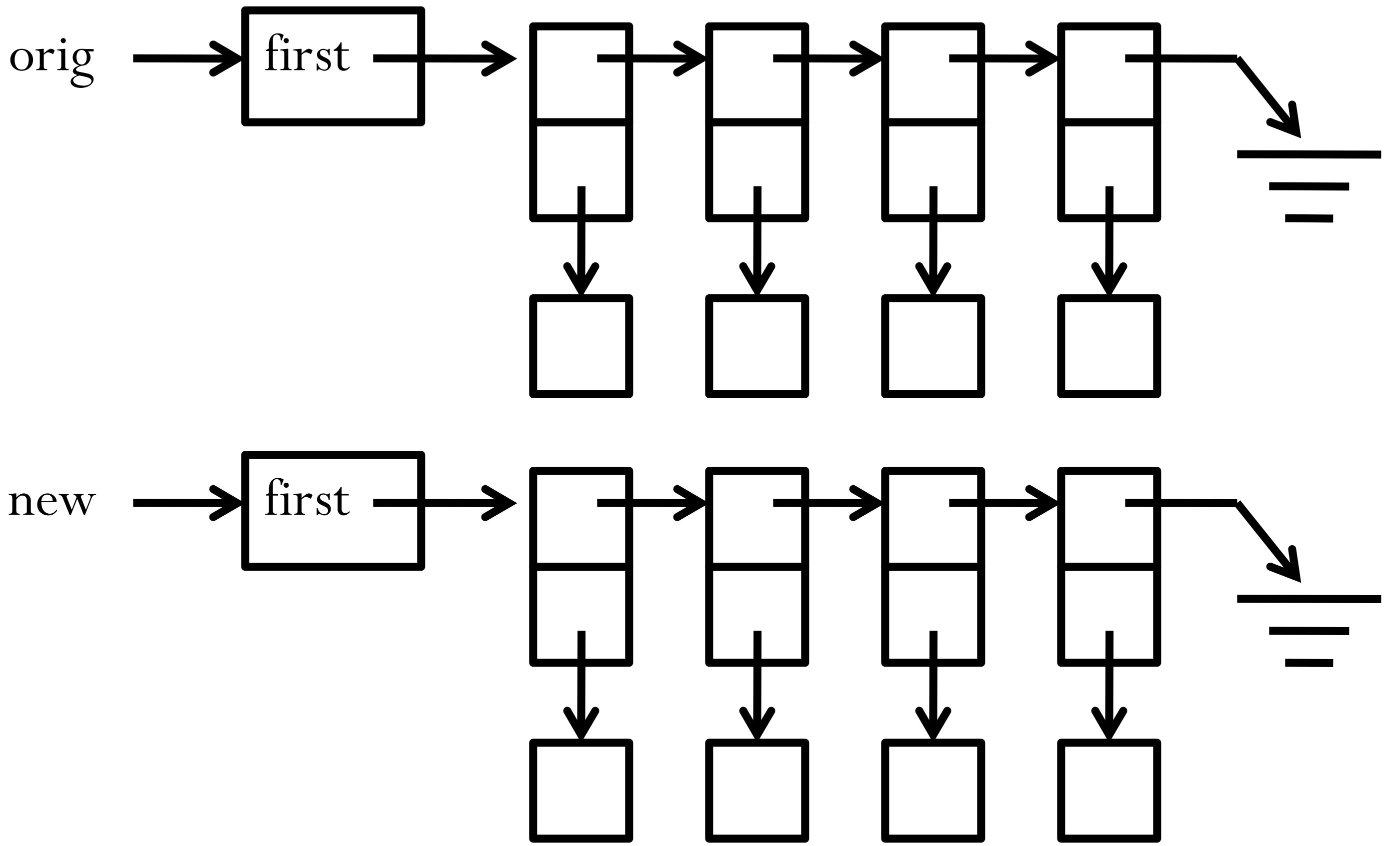
-> binds tighter than *

What does the blue statement mean?

Container of Pointers

Copy

- The list we would end up with is: **deep copy!**



Templated Container of Pointers

- Given container of pointers, the `List` template **must know** whether it is something that holds `T`'s or "pointers to `T`".

- The former **cannot** delete the values it holds, while the latter **must** do so.

- So, if we want to write a template class that holds pointer-to-T, we should provide a version based on pointer.

Containers

Templates

```
template <class T>
class PtrList {
  public:
    ...
    void insert(T *v);
    T     *remove();
  private:
    struct node {
        node *next;
        node *prev;
        T     *o;
    };
    ....
};
```

```
template <class T>
class ValList {
  public:
    ...
    void insert(T v);
    T     remove();
  private:
    struct node {
        node *next;
        node *prev;
        T      o;
    };
    ....
};
```

Containers

Templates

- This means that if we create two lists of BigThings:

```
ValList<BigThing> vbl;
PtrList<BigThing> pbl;
```

- Then the first list takes BigThings by value:

```
BigThing b;
vbl.insert(b);
```

- But the second list takes them as pointers:

```
BigThing *bp = new BigThing;
pbl.insert(bp);
```

This technique is preferable if you expect most (or even some) of your Lists to hold BigThings.

Containers

Templates

- This means that if we create two lists of `BigThing`s:

```
ValList<BigThing> vbl;
PtrList<BigThing> pbl;
```

- Then the first list takes `BigThing`s by value:

```
BigThing b;
vbl.insert(b);
```

- But the second list takes them as pointers:

```
BigThing *bp = new BigThing;
pbl.insert(bp);
```

However, it is **impossible** to have only a **single** implementation of `List` that can correctly contain things either as pointer or by value.

Outline

- Container of Pointers
- Polymorphic Containers
- Operator Overloading

Containers

Polymorphic containers

- Templates are checked at compile time, but when used straightforwardly, they cannot hold more than one kind of object at once, and sometimes this is desirable.
- There is another kind of container, called a "**polymorphic**" container, that **can** hold more than one type at once.
- The intuition behind polymorphic containers is that, because the container must contain **some** specific type, we'll manufacture a **special "contained" type**, and every real type will be a **subtype** of this contained type.

Containers

Polymorphic containers

- We are going to use derived class mechanism

```
class bar: public foo {
   ...
};
```

- Recall: a `bar*` can always be used where a `foo*` is expected, but not the other way around.

```
bar b;
foo *pf = &b;
```

Containers

Polymorphic containers

- We can take advantage of this by creating a "dummy class", called `Object`, that looks like this:

```
class Object {
  public:
    virtual ~Object() { };
};
```

- This defines a single class `Object` with a virtual destructor.
- Remember that if a method is virtual, it is also virtual in all derived classes.
- Why we need this? Because when a base-class pointer to a derived-class object is deleted (for example, in function **`removeAll()`**), it will call the destructor of the derived class.

Containers

Polymorphic containers

- Now, we can write a `List` that holds `Objects`:

```
struct node {
  node   *next;
  Object *value;
};

class List {
   ...
 public:
  void    insert(Object *o);
  Object *remove();
   ...
};
```

```
class Object {
 public:
  virtual ~Object() {};
};
```

Containers

Polymorphic containers

- To put `BigThing`s in a `List`, you define the class so that it is derived from `Object`:

```
class BigThing : public Object {
...
};
```

- By the derived class rules, a `BigThing*` can always be used as an `Object*`, but not the other way around.
- So the following works without complaint:

```
BigThing *bp = new BigThing;
l.insert(bp); // Legal due to
              // substitution rule
```

Containers

Polymorphic containers

- However, the compiler complains about the following because `remove()` returns an `Object *`; we cannot use a base class pointer when a derived class pointer is expected:

```
BigThing *bp;
bp = l.remove();
```

- However, we can do this:

```
Object *op;
BigThing *bp;

op = l.remove();
bp = dynamic_cast<BigThing *>(op);
...
```

Containers

Polymorphic containers

- The `dynamic_cast` operator does the following:

```
dynamic_cast<Type*>(pointer);
// EFFECT: if pointer's actual type is either
//    pointer to Type or some pointer to subtype
//    of Type, returns a pointer to Type.
//    Otherwise, returns NULL;
```

- So, after this cast, we `assert()` that the pointer is valid:

```
Object *op;
BigThing *bp;
op = remove();
bp = dynamic_cast<BigThing *>(op);
assert(bp);
```

Note: This only works for classes which have one or more virtual methods. That's okay, because `BigThing` will always have at least a virtual destructor.

Containers

Polymorphic containers

- Even with this, there is still one problem.
- This is a **container of pointers**, so we need **deep copy** for copy constructor and assignment operator
- The copyList() below just does shallow copy

```
List::List(const List &l) {
  first = NULL;
  copyList(l.first);
}
```

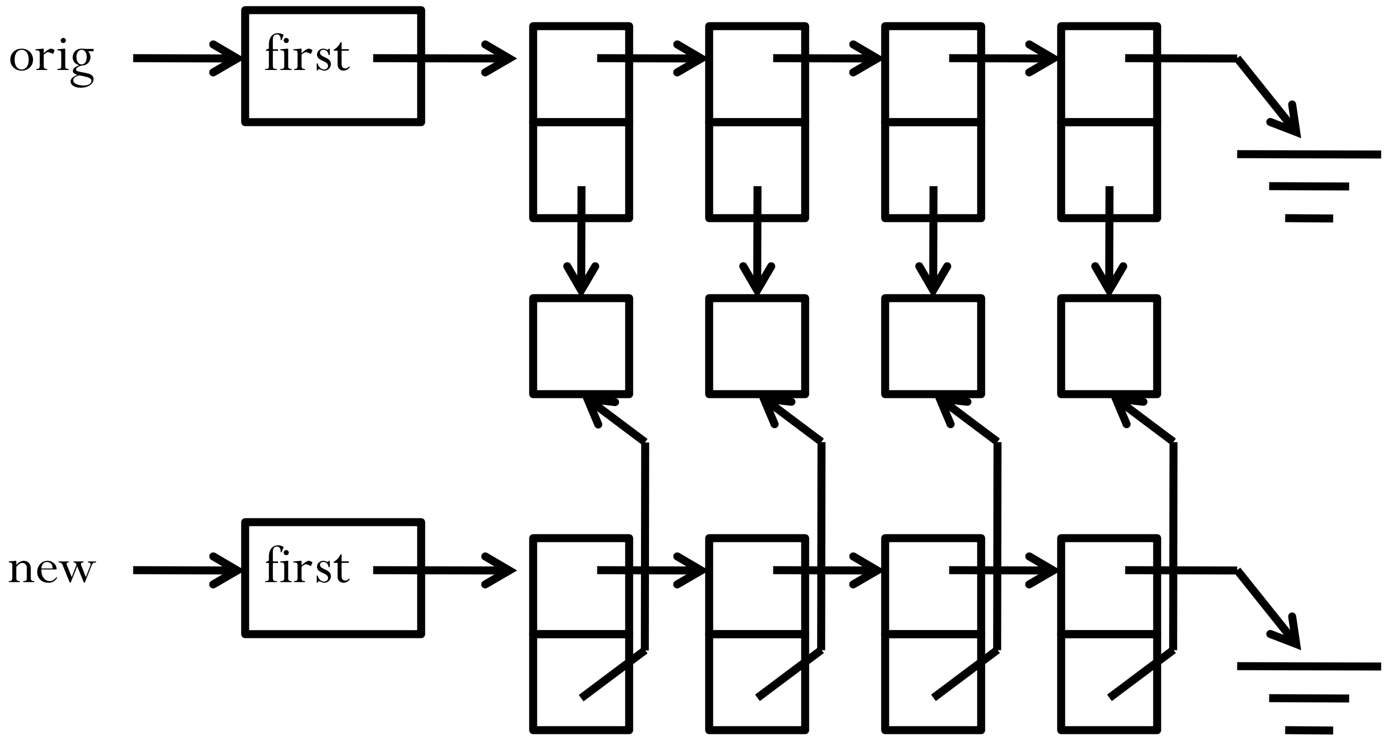
```
void List::copyList(node *list) {
  if (list != NULL) {
    copyList(list->next);
    insert(list->value);
  }
}
```

Object * type

Containers

Polymorphic containers

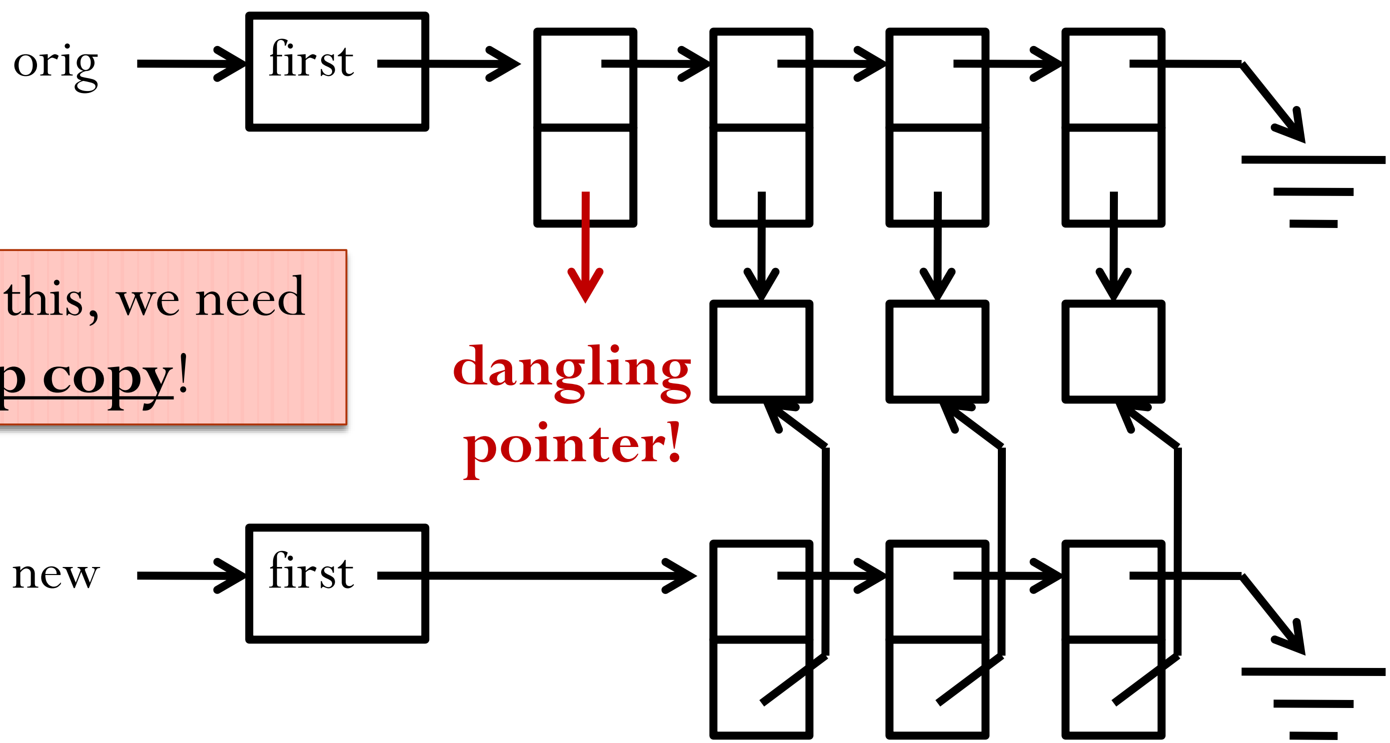
- Using the previous copyList(), the list we copied will be:



Containers

Polymorphic containers

- Now, if we remove the first item of the `new` list, we delete the first node, and return a pointer to it.
- The client, after removing that `Object`, will use it and delete it.
- Leaving us with this:



To fix this, we need a **<u>deep copy</u>**!

Containers

Polymorphic containers

- To fix this, we might be tempted to rewrite the copyList function to create a copy of the Object, as follows:

```
void List::copyList(node *list) {
  if (list != NULL) {
    Object *o;
    copyList(list->next);
    o = new Object(*list->value);
    insert(o);
  }
}
```

A BigThing object

- Unfortunately, this won't work, because `Object` does not have a constructor that takes `BigThing` as an argument.

Containers

Polymorphic containers

- The way to fix this is to use something called the "**named constructor idiom**".
  - **named constructor**: A method that (by convention) copies the object, returning a pointer to the "generic" base class.

- The name of this method (again, by convention) is usually "`clone`".

Containers

Polymorphic containers

- Modify the definition of `Object` to include a pure virtual **`clone()`** method:

```
class Object {
 public:
  virtual Object *clone() = 0;
    // EFFECT: copy this, return a pointer to it
  virtual ~Object() { };
};
```

- Declare that method **`clone()`** in `BigThing`, which **also** has a **copy constructor**:

```
class BigThing : public Object {
   ...
 public:
  Object *clone();
   ...
  BigThing(const BigThing &b);
}
```

Containers

Polymorphic containers

- `BigThing::clone()` can then call the correct copy constructor directly, and return a "generic" pointer to it:

```
Object *BigThing::clone() {
  BigThing *bp = new BigThing(*this);
  return bp;  // Legal due to substitution
              // rule
}
```

Containers

Polymorphic containers

- With this, we can finally rewrite copyList to use clone:

```
void List::copyList(node *list){
   if (list != NULL) {
      Object *o;
      copyList(list->next);
      o = list->value->clone();
      insert(o);
   }
}
```

- This gives us a true **deep copy** ☺

Outline

- Container of Pointers
- Polymorphic Containers
- Operator Overloading

Operator Overloading

Introduction

- C++ lets us **redefine** the meaning of the operators when applied to objects of **class type**.
- This is known as **operator overloading**.
- We have already seen the overloading of the assignment operator.

- Operator overloading makes programs much easier to write and read:

```
IntSet is;
int x = is[5]; // overload [] operator
         // access the IntSet element by index
cout << is << endl; // overload << operator
            // print all the IntSet elements
```

Operator Overloading
Basics

- Overloaded operators are functions with special names: the keyword **operator** followed by the symbol (e.g., +,-, etc.) of the operator being redefined.

- Like any other function, an overloaded operator has a return type and a parameter list.

```
A operator+(const A &l, const A &r);
```

Operator Overloading

Basics

- Most overloaded operators may be defined as ordinary **nonmember** functions or as class **member** functions.

```
A operator+(const A &l, const A &r);
// returns l "+" r
```

```
A A::operator+(const A &r);
// returns *this "+" r
```

- Overloaded functions that are members of a class may appear to have **one fewer** parameter than the number of operands.
  - Operators that are member functions have an implicit `this` parameter that is bound to the **first operand**.

Operator Overloading

Basics

- An overloaded **unary** operator has **no** (explicit) parameter if it is a member function and **one** parameter if it is a nonmember function.

- An overloaded **binary** operator would have **one** parameter when defined as a member and **two** parameters when defined as a nonmember function.

Example

- Overload **operator+=** for a class of complex number.

```
class Complex {
  // OVERVIEW: a complex number class
  double real;
  double imag;
public:
  Complex(double r=0, double i=0); // Constructor
  Complex &operator += (const Complex &o);
  // MODIFIES: this
  // EFFECTS: adds this complex number with the
  // complex number o and return a reference
  // to the current object.
};
```

Example

```
Complex &Complex::operator += (const Complex &o)
{
    real += o.real;
    imag += o.imag;
    return *this;
}
```

Example

- `operator+=` is a member function.
- We can also define a nonmember function that adds two numbers.

```
Complex operator + (const Complex &o1,
     const Complex &o2)
{
  Complex rst;
  rst.real = o1.real + o2.real;
  rst.imag = o1.imag + o2.imag;
  return rst;
}
```

- However, there is a problem with this. What is it?
- Since `operator+` is a nonmember function, it cannot access the private data members.

Friend

- So, we'll need some other mechanism to make the function as a "**friend**".
- The "friend" declaration allows you to expose the **private** state of one class to another function (and only that function) explicitly.

```
class foo {
  friend void baz();
  int f;
};
void baz() { ... }
```

The function `baz` has access to `f`, which would otherwise be private to class `foo`.

Friend

- So, we'll need some other mechanism to make the function as a "**friend**".
- The "friend" declaration allows you to expose the **private** state of one class to another function (and only that function) explicitly.

```
class foo {
  friend void baz();
  int f;
};
void baz() { ... }
```

Note: a friend function is **NOT** a member function; it is an ordinary function.

Note: NOT `void foo::baz() { ... }`

Friend

- So, we'll need some other mechanism to make the function as a "**friend**".
- The "friend" declaration allows you to expose the **private** state of one class to another function (and only that function) explicitly.

```
class foo {
  friend void baz();
  int f;
};
void baz() { ... }
```

Note: "`friend void baz();`" goes inside `foo`. It means `foo` gives friendship to function `baz()`.

Friend

- Besides function, we can also declare a class to be friend.

```
class foo {
  friend class bar;
  int f;
};
class bar {
  ...
};
```

Then, objects of class `bar` can access private member `f` of `foo`.

Friend

```
class foo {
  friend class bar;
  friend void baz();
  int f;
};
class bar { ... };
void baz() { ... }
```

Friendship of both class and function.

- Note: Although "**friendship**" is declared inside `foo`, `bar` and `baz()` are not the members of `foo`!
- "**friend**" declaration may appear anywhere in the class.
  - It is a good idea to **group** friend declarations **together** either at the beginning or end of the class definition.

Example

- In our example of complex number class, we will declare `operator+` as a friend:

```
class Complex {
  // OVERVIEW: a complex number class
  double real;
  double imag;
public:
  Complex(double r=0, double i=0);
  Complex &operator += (const Complex &o);
  friend Complex operator+(const Complex &o1,
        const Complex &o2);
};
```

Its implementation is the same as before.

Reference

- **C++ Primer (4th Edision)**, by *Stanley Lippman, Josee Lajoie, and Barbara Moo*, Addison Wesley Publishing (2005)
  - Chapter 12.5 Friends
  - Chapter 14 Overloaded Operations and Conversions