

VE280 Programming and Elementary Data Structures

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Deep Copy



Learning Objectives

- Understand the difference between a shallow copy and a deep copy
- Know how to implement deep copy by redefining the copy constructor and the assignment operator

Outline


- Shallow Copy versus Deep Copy
- Copy Constructor
- Assignment Operator

Dynamic Arrays

Group Exercise

- **Question**: What happens in the following code?
- **Hint**: Classes are passed by-value, just like structs. They are also bitwise-copied, just like structs!

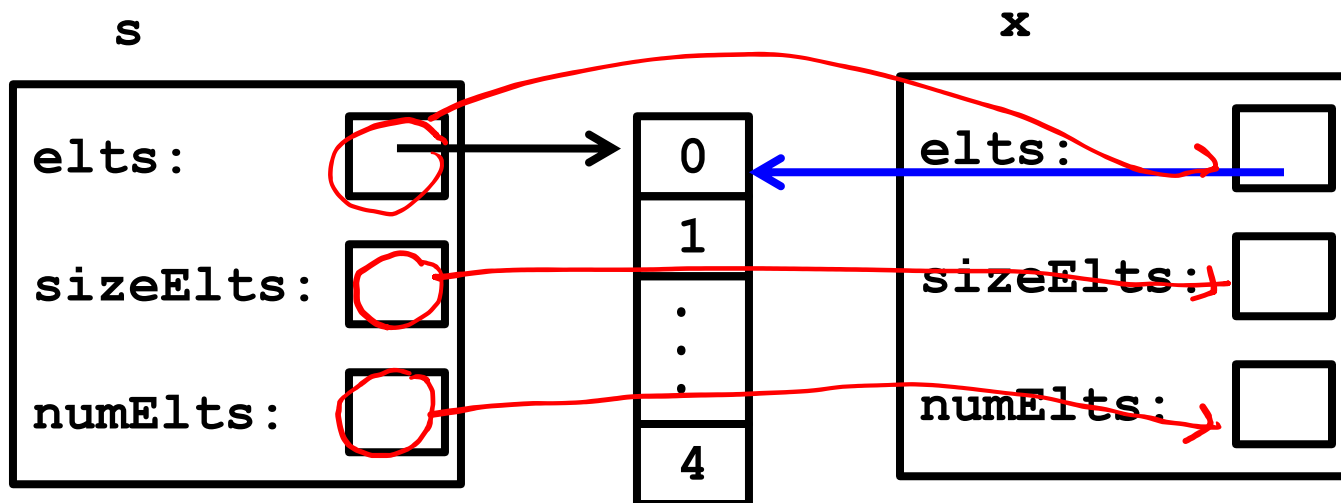
```
void foo(IntSet x) {  
    // do something  
}  
  
int main() {  
    IntSet s;  
    s.insert(5);  
    foo(s);  
    s.query(5);  
}
```



Dynamic Arrays

The problem of dangling pointers

- The result of pass-by-value mechanism: only pointer value of `elts` is copied, not the array `elts[]`.
 - The two objects end up sharing the same `elts[]` array!
- When `foo` finishes, `x` goes out of scope and is **destroyed**. As a result, `s.elts` **dangles**.
- When `main` finishes, the destructor of `s` is called. This causes double-deletion of `s.elts`.



Dynamic Arrays

The problem of dangling pointers

- It turns out that exactly the same thing happens in the following:

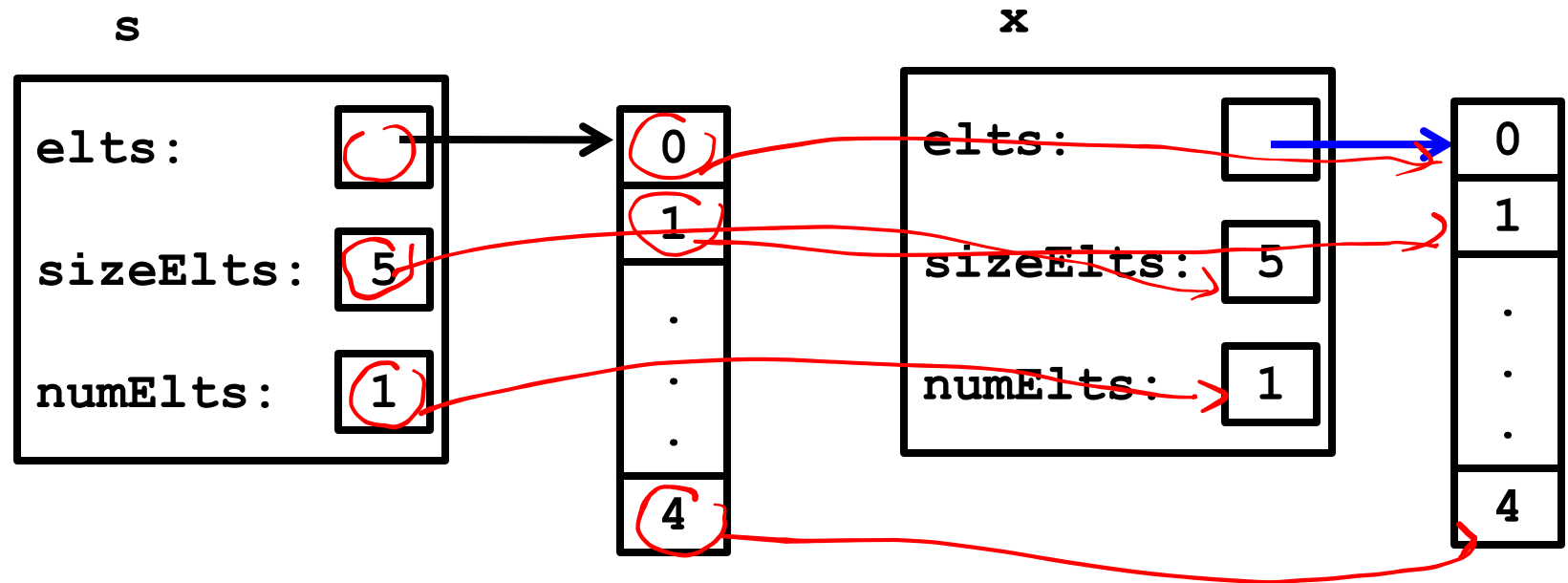
```
void foo() {  
    IntSet s(5);  
    s.insert(7);  
    {  
        IntSet x;  
        x = s;  
    }  
    s.query(7); // Undefined!  
}
```

- The assignment statement copies the elements of `s` to the elements of `x`, but they end up **sharing** the `elts` array. When `x` goes out of scope and is **destroyed**, `s.elts` **dangles**.

Dynamic Arrays

Fixing dangling pointers

- What we really want is to copy the entire **array**.



Dynamic Arrays

Fixing dangling pointers

- When a class contains pointers to **dynamic** elements, copying it is tricky.
- If we just copy the "members of the class", we get a **shallow copy**.
- Usually, we want a **full** copy of **everything**. This is called a **deep copy**.

Outline

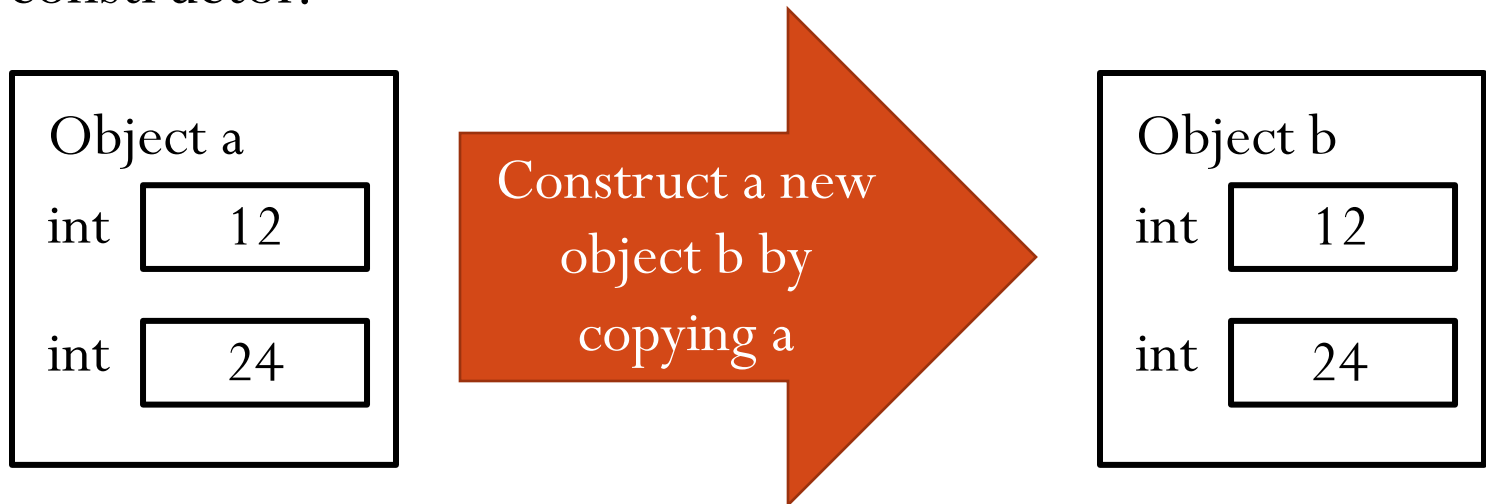
- Shallow Copy versus Deep Copy
- Copy Constructor
- Assignment Operator

Fixing Dangling Pointers

- The C++ class mechanism provides two very closely related mechanisms that copy class objects:
 - **Copy constructor** and **assignment operator**.

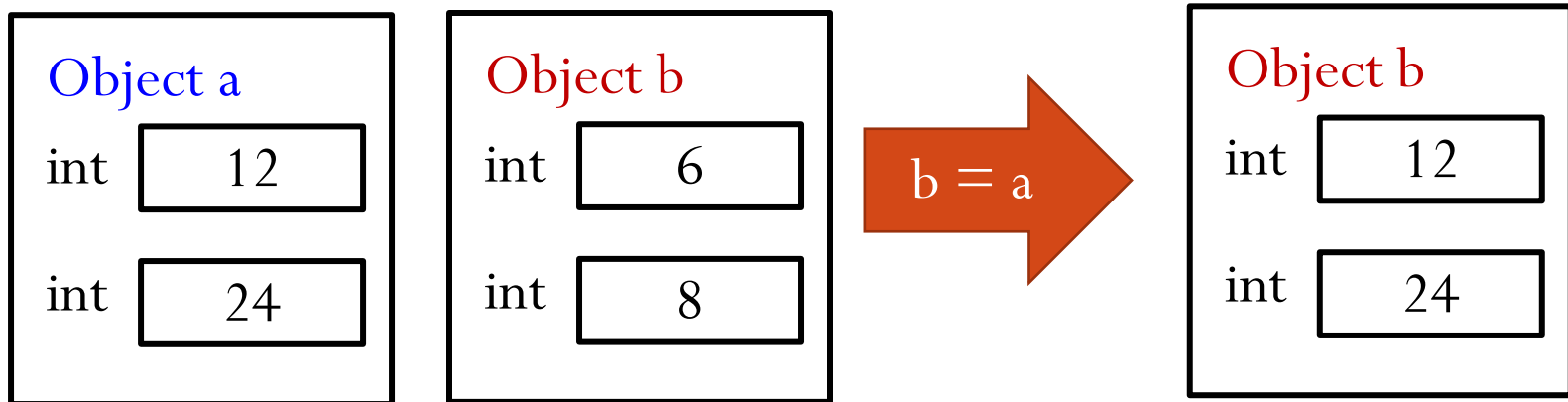
Fixing Dangling Pointers

- **Copy constructor** – it creates an object of this class by copying from another object of this class.
 - In other words, given a “blank” block of memory, and an “example” instance, make the “blank” block a copy of the example.
- The copy constructor plays a role identical to any other constructor.



Fixing Dangling Pointers

- **Assignment operator** – it copies the contents from one object (source) to another **existing** object (target).
 - Both objects already exist.



Copy Constructors

- We could declare a copy constructor for our `IntSet` class as follows:

```
class IntSet {  
    int *elts;      // array of elements  
    int numElts;    // number of elements in array  
    int sizeElts;   // capacity of array  
public:  
    IntSet(int size=MAXELTS); // client optionally  
                                // names size  
    IntSet(const IntSet &is); // copy constructor  
    ...  
};
```

function overloading

Copy Constructors

IntSet(const IntSet &is) ;

- When passing arguments by value to a function, copy constructor is called.
- The copy constructor is invoked on a “blank” instance of an IntSet, and must make the “blank” version look like an exact copy of the argument.

`foo(s); //s is an IntSet`

```
void foo(IntSet x) {  
    // copy constructor copies s to x  
    // do something  
}
```

Copy Constructors

```
IntSet(const IntSet &is) ;
```

- The argument must be **passed by reference** to avoid infinite recursion.
- The argument is **const** for two reasons:
 1. Avoid accidentally changing the argument.
 2. Ensure that any instance (e.g., const object) of the class can serve as the **source**, not just a **lvalues**.

Copy Constructors

- The copy constructor has to accomplish the following tasks:
 1. Allocate an array of the same size as the source set's ✓
 2. Copy each element from the source array to the new array ✓
 3. Copy the numElts/sizeElts fields ✓
- The copying part is going to have to happen in both the **copy constructor** and the **assignment operator**.
- So, we will abstract away the copying into a utility function.

Copy Constructors

- This adds a private method to our ADT:

```
class IntSet {
    int *elts;    // array of elements
    int numElts;  // number of elements in array
    int sizeElts; // capacity of array
    void copyFrom(const IntSet &is);
        // MODIFIES: this
        // EFFECTS:  copies is' contents to this
public:
    IntSet(int size=MAXELTS); // client optionally
                               // names size
    IntSet(const IntSet &is); // copy constructor
    ...
};
```

Copy Constructors: Deep Copies

- Before implementing `copyFrom`, think about what has to happen in `copyFrom`, **in general**, not just in the context of the **copy constructor**.
- We need to figure this out because `copyFrom` will be called from the **assignment operator**.

Copy Constructors: Deep Copies

- `copyFrom` is a method and it must maintain the representation invariants. Here's what it must do:
 1. `copyFrom` has to assume that the source and destination sets might have different sizes. If so, it will have to resize the array appropriately, by **destroying** and **reallocating** it. ✓
 2. Copy the source array to the destination array. ✓
 3. Copy `sizeEltS` and `numEltS`. ✓

Copy Constructors: Deep Copies

```
void IntSet::copyFrom(const IntSet &is) {  
    if (is.sizeElts != sizeElts) { // Resize array  
        delete[] elts;  
        sizeElts = is.sizeElts;  
        elts = new int[sizeElts];  
    }  
    // Copy array  
    for (int i = 0; i < is.sizeElts; i++) {  
        elts[i] = is.elts[i];  
    }  
    // Establish numElts invariant  
    numElts = is.numElts;  
}
```

It is OK to visit `is.sizeElts` in `copyFrom`, since `copyFrom` is a member function of `IntSet`

Copy Constructors: Deep Copies

- With `copyFrom`, the copy constructor is simple.
- First, we have to establish its invariants, then call `copyFrom`.

```
IntSet::IntSet(const IntSet &is) {  
    elts = NULL;  
    numElts = 0;  
    sizeElts = 0;  
    copyFrom(is);  
}
```

```
IntSet::IntSet(const IntSet &is):  
    elts(NULL), sizeElts(0), numElts(0) {  
    copyFrom(is);  
}
```

Copy Constructors: Deep Copies

- Contrast this copy constructor with the "default" method of copying, which does only a few things:
 - Copies the elts/numElts/sizeElts fields
- The copy constructor we've written **chases** pointers and **copies** the things they point to, rather than just copying the pointers.
- This is called a **deep copy**, as opposed to the default behavior of a **shallow copy**.



Select all the correct answers

Let `SetOfIntSet` be a newly-defined class that is a set of `IntSet`. The set in `SetOfIntSet` is also defined as a dynamic array. We were careful enough to define a copy constructor in `SetOfIntSet` (using a code similar to `copyFrom`) to be able to deep copy its instances.

- **A.** The copy constructor performs a deep copy.
- **B.** The copy constructor performs a shallow copy.
- **C.** On some instances of `SetOfIntSet`, the copy constructor performs a deep copy.
- **D.** On some instances of `SetOfIntSet`, the copy constructor performs a shallow copy.

Outline

- Shallow Copy versus Deep Copy
- Copy Constructor
- Assignment Operator

Assignment Operators

Basics

- Assignment statement returns a value. ✓
- The value is the **reference** to its left-hand-side object.

- Example

x = 4; ✓

(y = x) += 2; \Leftrightarrow $\begin{cases} y = x; \\ y += 2; \end{cases}$

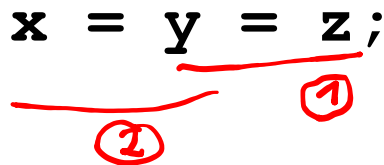
- Are the above statements legal? *yes*
- What is the value of y? *6*

Assignment Operators

Basics

- Assignment statements can be “chained”. The following is legal in C++:

x = y = z;



- This is a compound expression. Assignment operators binds **right-to-left**.
- Because "=" binds right-to-left, we first assign z to y, and this expression yields the (new) value "y" so that it can in turn be assigned to x.

Assignment Operators

On to overloading

- Now, how do we handle the following code?

```
IntSet s1(5);
```

```
IntSet s2(10);
```

```
s1 = s2; // assignment of s2 to s1
```

- By default, the compiler will use a shallow copy for this.
- However, like a copy constructor, assignment must do a deep copy of the right-hand-side to the left-hand-side.
- To implement this, we **redefine** the "assignment operator" for IntSet by doing **operator overloading**.

Assignment Operators

Operator overloading

- Here's how we **overload** the assignment operator:

```
class IntSet {  
    // data elements  
    ...  
    public:  
    // Constructors  
    ...
```

```
→ IntSet &operator= (const IntSet &is);  
    ...  
};
```

You can overload other operators such as +, *, etc. You need to use the keyword **operator**

Assignment Operators

Operator overloading

```
IntSet &operator= (const IntSet &is);
```

- Like the copy constructor, the assignment operator takes a **reference to a const** instance to copy from.
- However, it also **returns** a **reference** to the copied-to object.
- When we call the assignment operator
$$a = b;$$
- Essentially, we call the assignment operator of object a.
- b is the argument to the `operator=()` function.
 - Consider this as `a.operator=(b)`

Assignment Operators

Operator overloading

- The cool thing is that we have written `copyFrom` already:

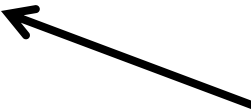
```
void IntSet::copyFrom(const IntSet &is) {  
    if (is.sizeElts != sizeElts) { // Resize array  
        delete[] elts;  
        sizeElts = is.sizeElts;  
        elts = new int[sizeElts];  
    }  
    // Copy array  
    for (int i = 0; i < is.sizeElts; i++) {  
        elts[i] = is.elts[i];  
    }  
    // Establish numElts invariant  
    numElts = is.numElts;  
}
```

Assignment Operators

Operator overloading

- With `copyFrom`, the assignment operator is (almost) trivial:

```
IntSet &IntSet::operator= (const IntSet &is) {  
    copyFrom(is);  
    return *this;  
}
```



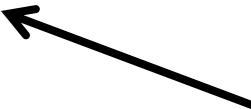
Note: Every method has an implicit local variable "this", which is a pointer to the current instance on which that method operates.

Assignment Operators

Operator overloading

- With `copyFrom`, the assignment operator is (almost) trivial:

```
IntSet &IntSet::operator= (const IntSet &is) {  
    copyFrom(is);  
    return *this;  
}
```



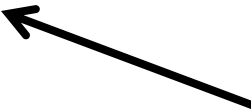
Note: This line dereferences that pointer and then returns a reference to it. We can't just return “this”, because “this” is just a pointer, cannot be used as a reference.

Assignment Operators

Operator overloading

- With `copyFrom`, the assignment operator is (almost) trivial:

```
IntSet &IntSet::operator= (const IntSet &is) {  
    copyFrom(is);  
    return *this;  
}
```



Note: We must return the reference to the **assigned-to** object, not the **assigned-from** object, i.e., we cannot return `is`.

Assignment Operators


Question

- Question: What happens if we do this?

```
IntSet s(50);
```

```
s = s;
```

- It is fine! Since their `sizeEltS` are equal, no destroying and reallocating are needed.
- However, it is better to modify the code as follows:

```
IntSet &IntSet::operator= (const IntSet &is) {  
    if(this != &is)   
        copyFrom(is);  
    return *this;  
}
```



Which of the following statements are true about operator overloading?

Select all the correct answers.

- **A.** The code can become more legible.
- **B.** The code can become illegible. ✓
- ~~C.~~ It is possible to perform operations that wouldn't be possible otherwise.
- **D.** We can always avoid operator overloading.

The Rule of the Big Three

- What we have talked so far can be summarized with a simple rule: **the Rule of the Big Three**.
- Specifically, if you have any **dynamically allocated storage** in a class, you must provide:
 - **A destructor**
 - **A copy constructor**
 - **An assignment operator**
- If you find yourself writing one of these, you almost certainly need all of them.

Reference

- **Problem Solving with C++ (8th Edition)**, by *Walter Savitch*, Addison Wesley Publishing (2011)
 - Chapter 11.4 **Classes and Dynamic Arrays**
- Course notes, pages 148-159