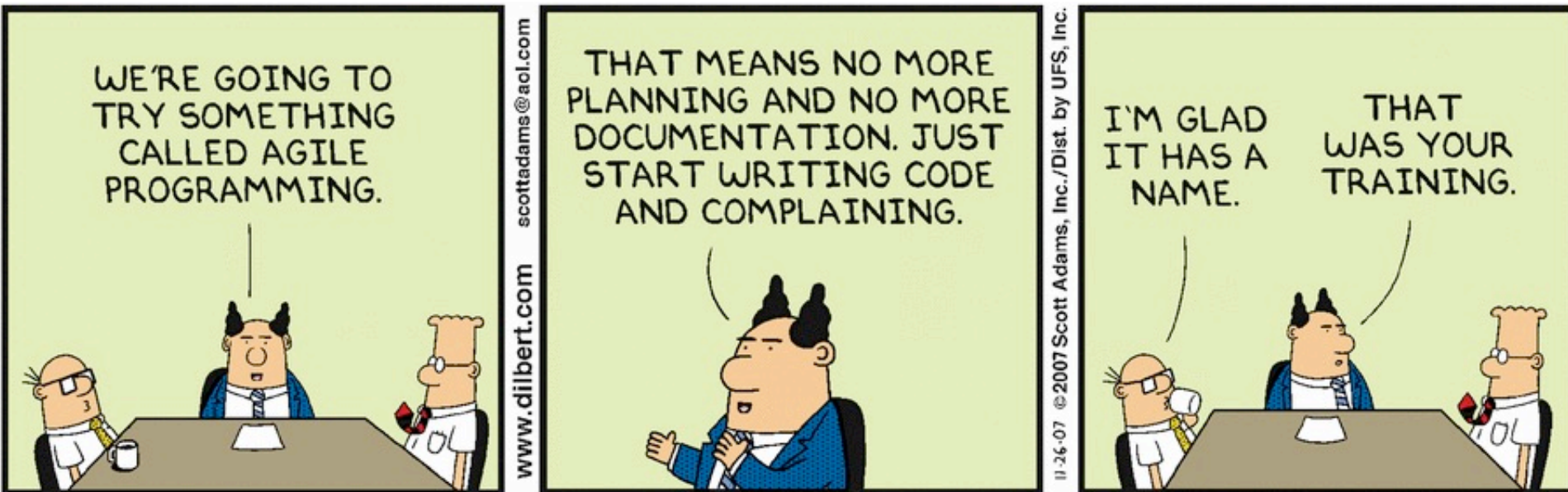


VE280 Programming and Elementary Data Structures

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Final Review



Final Exam

- August 4th, 2020, 6:20pm – 8pm
- Closed book
- No electronic devices
- Read carefully the instructions and the questions

Final Exam

- Written exam
 - Like previous years
 - A number of questions which only require you to provide a very short answer
 - A few questions which require you to write code on the paper
- Abide by the **Honor Code!**

Final Exam Topics

Range: Everything after Midterm

- Subtype and inheritance
- Virtual function
- Abstract base class (interface)
- Representation invariants
- Dynamic memory management and dynamic array
- Constructor taking default arguments and destructor
- Deep copy: copy constructor, overloaded assignment operator
- Linked list
- Template
- Container of pointers: one invariant and three rules
- Operator overloading
- Stack and queue
- STL

Subtypes

Creating

- Subtype: satisfying “substitution principle”
- In an Abstract Data Type, there are three ways to create a subtype from a supertype:
 1. Add one or more operations. E.g. $\text{IntSet} \rightarrow \text{MaxIntSet}$
 2. **Strengthen** the **postcondition** of one or more operations. E.g., $\text{MaxIntSet} \rightarrow \text{SafeMaxIntSet}$
 3. **Weaken** the **precondition** of one or more operations. E.g., $\text{MaxIntSet} \rightarrow \text{SafeMaxIntSet}$

Inheritance

- C++ has a mechanism to enable subtyping, called **inheritance**.

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

- bar is a **derived class** of foo
- Legal to have

```
bar b;  
foo &fr = b;  
foo *fp = &b;
```

- **Protected** data members
 - Versus private data members

Virtual Functions

```
class IntSet {  
    ...  
public:  
    ...  
    virtual void insert(int v);  
    ...  
};
```

- This makes it possible to run the function based on the actual type.
- “virtualness” is inherited.

Virtual Functions

```
class foo {  
public:  
    void f();  
    virtual void g();  
};  
class bar: public foo {  
public:  
    void f();  
    void g();  
};
```

non-virtual

virtual

```
bar b;  
foo *fp = &b;  
fp->f(); //Call foo::f()  
fp->g(); //Call bar::g()
```


Abstract Base Classes

- An "interface-only" class, from which an implementation can be **derived**.
- Cannot be instantiated, because there is no implementation.
- Define **pure virtual functions** for abstract base classes.
virtual void insert(int v) = 0;
- Put the implementation in a **derived class**.
`class IntSetImpl : public IntSet`
- Create instance using pointers/references.
`IntSet *getIntSet();`

Representation Invariants

- A **representation invariant** applies to the data members of ADT.
- It describes the conditions that must hold on those members for the representation to correctly implement the abstraction.
- Essentially, for each method, you should:
 - Do the work of the method (i.e. insert)
 - Repair the invariants you broke
- Invariants can be coded, to check the sanity of the structure.
 - To check: `assert (repOK ()) ;`

Dynamic Memory Allocation

- Dynamic objects, about which the compiler doesn't know
 - **How big it is.**
 - **How long it lives.**
- Dynamic storage management: **new** and **delete**
- Memory leak problem
- Checking memory leak: **valgrind**
- Dynamic Arrays

```
int *ia = new int[5];  
delete[] ia;
```

- Note: difference between **delete** and **delete[]**

IntSet with Dynamic Array

- Overloaded Constructor
 - **IntSet() ;**
 - **IntSet(int size) ;**
- Calling constructor
 - IntSet is1 ;**
 - IntSet is2(200) ;**

IntSet with Dynamic Array

- Function with Default Argument

```
IntSet(int size = MAXELTS);
```

```
int f(int a, int b = 3, int c = 4);  
f(2, 5); a = 2, b = 5, c = 4
```

- There could be multiple default arguments in a function, but they must be the last arguments.

```
int add(int a, int b = 0, int c = 1) // OK
```

```
int add(int a, int b = 1, int c) // Error
```

- Destructor

- **~IntSet();**

- Automatically called

Deep Copy

- Shallow Copy versus Deep Copy
 - We need to copy the dynamic array, not just the array pointer.

- Copy Constructor

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

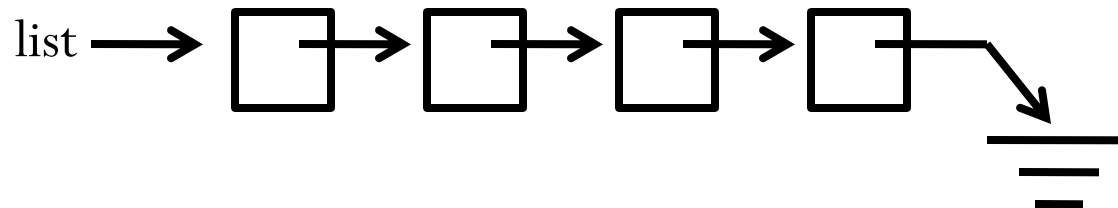
- Assignment Operator

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

- Assignment returns a **reference** to the left-hand-side object.
- Can handle self-assignment correctly by first checking
if(this != &is)
- **return *this ;**
- The Rule of the Big Three
 - destructor, copy constructor, and assignment operator

Linked List

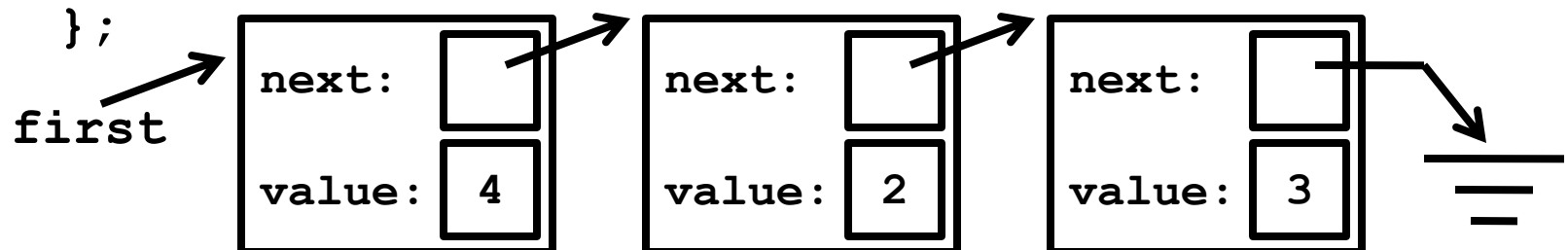
- A linked list is one with a series of zero or more data containers, connected by pointers from one to another, like:



- Implementation of Linked List

```
class IntList {  
    node *first;  
    public:  
    ...  
};
```

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



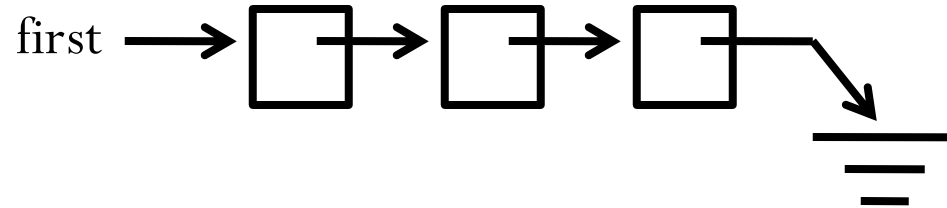
Linked Lists

```
class IntList {
    node *first;
public:
    bool isEmpty();
    void insert(int v);
    int remove();
    IntList(); // default ctor
    IntList(const IntList& l); // copy ctor
    ~IntList(); // dtor
    // assignment
    IntList &operator=(const IntList &l);
};
```

- Variations of linked lists.

Linked List Traversal

- With the “first” pointer, we can traverse the linked list.



```
int IntList::getSize() {  
    int count = 0;  
    node *current = first;  
    while(current) {  
        count++;  
        current = current->next;  
    }  
    return count;  
}
```

Traverse
through the list.

Polymorphism and Templates

- Things like `IntSet` and `IntList` are often called **containers** or **container classes**.
 - We can also define `CharList`.
- Reusing code for different types is called **polymorphism**.

```
template <class T>
class List {
    ...
};
```

Templates

- Each **method** must also be declared as a "**templated**" method.

```
template <class T>
void List<T>::isEmpty() {
    return (first == NULL);
}
```

- To use templates, you specify the type T when creating the container object.

```
List<int> li;
```

Container of Pointers

- Instead of copying large types by value, we usually insert and remove them **by reference**.

```
void  insert(BigThing *v) ;  
BigThing *remove() ;
```

- At-most-once invariant.
- Existence, ownership, and conservation rules.

Containers

Destructor

```
template <class T>
List<T>::~~List() {
    while (!isEmpty()) {
        T *op = remove();
        delete op;
    }
}
```

Container of Pointers

Copy

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

Operator Overloading

- C++ lets us **redefine** the meaning of the operators when applied to objects of **class type**.
- 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
```

Friend

- A mechanism to make a function/class as a "**friend**" of another class, so the function/class can directly visit the private members of the other class

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

Friendship of both
class and function.

Stack

- A “pile” of objects where new object is put on **top** of the pile and the top object is removed first.
- Five operations
 - `size()`, `isEmpty()`, `push()`, `pop()`, `top()`
- Can be implemented using either array or linked list
- Applications
 - Web browser’s “back” feature
 - Parentheses matching

Queue

- A “line” of items in which the **first** item inserted is the **first** one out.
 - Insert to the back and remove from the front
- Six operations
 - `size()`, `isEmpty()`, `enqueue()`, `dequeue()`, `front()`, `rear()`
- Can be implemented using either linked list or array
 - What kind of linked list?
 - What kind of array?
- Application: wire routing in electronic design automation

Standard Template Library

- Sequential container: store and retrieve elements by position
 - vector, deque, list
- Associative container: store and retrieve elements based on their **keys**. We focus on two associative containers where the order depends on the keys of the elements:
 - map, set
- Iterators: companion type of a container
 - Iterators are more general than subscripts: All of the library containers define iterator types, but only a few of them support subscripting.
 - Operations: ++iter, --iter, iter1 == iter2, iter1 != iter2, *iter
 - const_iterator: cannot change the element referred to

Sequential Container: vector

- Constructor
 - `vector<T> v1; vector<T> v2 (v1) ;`
 - `vector<T> v3 (n, t) ;`
 - `vector<T> v4 (b, e) ;`
 - Iterator range. Can even use another container type / built-in array to initialize
- Random access through subscripting: `d [k]`
- `size()`, `empty()`, `push_back()`, `pop_back()`, `front()`, `back()`, `begin()`, `end()`, `clear()`
- Supports iterator arithmetic (`iter+3`) and relational operations on iterator (`iter1 </<=>/>= iter2`)

Differences between vector, deque, list

- deque and list support `push_front()` and `pop_front()`; vector does not support

- **list** does not support subscripting

```
list<string> li(10, "hi");  
li[1] = "hello"; // Error!
```

- No iterator arithmetic for **list**

```
list<int>::iterator it;  
it+3; // Error!
```

- No relational operation `<`, `<=`, `>`, `>=` on iterator of **list**

```
list<int>::iterator it1, it2;  
it1 < it2; // Error!
```

Which Sequential Container to Use?

- `vector` and `deque` are fast for random access, but are not efficient for inserting/removing at the middle
- `list` is efficient for inserting/removing at the middle, but not efficient for random access
- Choose based on the required operations and their frequencies
 - Use `vector`, unless you have a good reason to prefer another container.

Associative Container: map

- It stores (key, value) pair
- **map<string, int> word_count;**
- We can use subscripting to add elements to a map
word_count["Anna"] = 1;
 - If key exists, subscripting return the value
 - If not existing, adds an element with that index to the map
- How can we determine if a key is present without causing it to be inserted?
 - **m.find(k)**
- Iterator for map elements
 - **iter->first; iter->second;**

Good Luck to Everyone!

Questions?

Sample Question 1

- Consider the following class Foo:

```
class Foo{
    IntSet set;
public:
    Foo() {
        set = IntSet();
    }
    // other members are omitted
};
```

- How many times is the constructor of IntSet called when the default constructor of Foo is called?

Sample Question 2

- For the following code, there is **at most one** major problem. If there is one, write down the problem. You don't need to tell us how to fix it. If there is none, write "None".

```
vector<string> ds;  
ds.push_back("toto");  
ds.push_back("tata");  
stack<string> s(ds);  
s.pop();
```

Sample Question 3

- A circular list can be defined as follows:

```
template<class T> class CircularList { // OVERVIEW: a circular singly-linked list
    struct Node{
        Node *next; // next node, NULL if empty
        T val; // value contained by this node
    };
    node *last; // pointer to the last node of the list
public: /* Other member functions are omitted */
    void insert(T v);
    // MODIFIES: this
    // EFFECTS: Add the value v to the front of the list.
    T remove();
    // MODIFIES: this
    // EFFECTS: If the list is empty, throws a ListEmpty exception.
    //             Otherwise, remove the first node of the list and
    //             return its value
    unsigned int size() const;
    // EFFECTS: Return the number of elements in the list.
};
```

```
class ListEmpty {
    // OVERVIEW: an exception class
};
```

- Why do we keep a pointer to the last node (instead of the first)?
- Give the representation invariant
- Implement the insert and remove methods