

CSCI-1200 Data Structures — Spring 2020

Lecture 11 — Doubly-Linked Lists

Today's Lecture

- Limitations of singly-linked lists
- Doubly-linked lists: Structure, Insert, & Remove
- Our own version of the STL `list<T>` class, named `dslist`, Implementing list iterators
- Common mistakes, STL List w/ iterators vs. “homemade” linked list with Node objects & pointers

10.13 Basic Mechanisms: Pushing on the Back

- Goal: place a new node at the end of the list.
- We must step to the end of the linked list, remembering the pointer to the last node.
 - This is an $O(n)$ operation and is a major drawback to the ordinary linked-list data structure we are discussing now. We will correct this drawback by creating a slightly more complicated linking structure in our next lecture.
- We must create a new node and attach it to the end.
- We must remember to update the `head` pointer variable's value if the linked list is initially empty.
 - Hence, in writing the function, we must pass the pointer variable **by reference**.

10.14 Exercise: Write `push_front`

```
template <class T> void push_front( Node<T>* & head, T const& value ) {
```

- If the input linked list chain contains n elements, what is the order notation of the implementation of `push_front`?

10.15 Exercise: Write `push_back`

```
template <class T> void push_back( Node<T>* & head, T const& value ) {
```

- If the input linked list chain contains n elements, what is the order notation of this implementation of `push_back`?

10.16 Inserting a Node into a Singly-Linked List

- With a singly-linked list, we'll need a pointer to the node *before* the spot where we wish to insert the new item.
- If **p** is a pointer to this node, and **x** holds the value to be inserted, then the following code will do the insertion. Draw a picture to illustrate what is happening.

```
Node<T> * q = new Node<T>; // create a new node
q -> value = x;             // store x in this node
q -> next = p -> next;      // make its successor be the current successor of p
p -> next = q;              // make p's successor be this new node
```

- Note: This code will not work if you want to insert **x** in a new node at the *front* of the linked list. Why not?

10.17 Removing a Node from a Singly-Linked List

- The remove operation itself requires a pointer to the node *before* the node to be removed.
- Suppose **p** points to a node that should be removed from a linked list, **q** points to the node before **p**, and **head** points to the first node in the linked list. Note: Removing the first node is an important special case.
- Write code to remove **p**, making sure that if **p** points to the first node that **head** points to what was the second node and now is the first after **p** is removed. Draw a picture of each scenario.

10.18 Exercise: Singly-Linked List Copy

Write a *recursive* function to copy all nodes in a linked list to form an new linked list of nodes with identical structure and values. Here's the function prototype:

```
template <class T> void CopyAll(Node<T>* old_head, Node<T>*& new_head) {
```

10.19 Exercise: Singly-Linked List Remove All

Write a *recursive* function to delete all nodes in a linked list. Here's the function prototype:

```
template <class T> void RemoveAll(Node<T>*& head) {
```

11.1 Basic Linked Lists Mechanisms: Common Mistakes

Here is a summary of common mistakes. Read these carefully, and read them again when you have problem that you need to solve.

- Allocating a new node to step through the linked list; only a pointer variable is needed.
- Confusing the `.` and the `->` operators.
- Not setting the pointer from the last node to `NULL`.
- Not considering special cases of inserting / removing at the beginning or the end of the linked list.
- Applying the `delete` operator to a node (calling the operator on a pointer to the node) before it is appropriately disconnected from the list. Delete should be done after all pointer manipulations are completed.
- Pointer manipulations that are out of order. These can ruin the structure of the linked list.
- Trying to use STL iterators to visit elements of a “home made” linked list chain of nodes. (And the reverse.... trying to use `->next` and `->prev` with STL list iterators.)

11.2 Limitations of Singly-Linked Lists

- We can only move through it in one direction
- We need a pointer to the node *before* the spot where we want to insert and a pointer to the node *before* the node that needs to be deleted.
- Appending a value at the end requires that we step through the entire list to reach the end.

11.3 Generalizations of Singly-Linked Lists

- Three common generalizations (can be used separately or in combination):
 - Doubly-linked: allows forward and backward movement through the nodes
 - Circularly linked: simplifies access to the tail, when doubly-linked
 - Dummy header node: simplifies special-case checks
- Today we will explore and implement a doubly-linked structure.

11.4 Transition to a Doubly-Linked List Structure

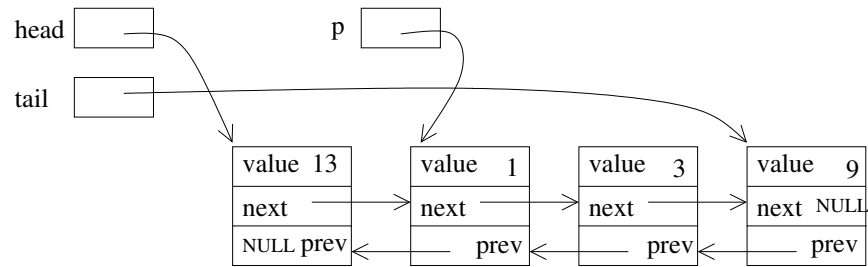
- The revised `Node` class has two pointers, one going “forward” to the successor in the linked list and one going “backward” to the predecessor in the linked list. We will have a `head` pointer to the beginning *and* a `tail` pointer to the end of the list.

```
template <class T> class Node {
public:
    Node() : next_(NULL), prev_(NULL) {}
    Node(const T& v) : value_(v), next_(NULL), prev_(NULL) {}
    T value_;
    Node<T>* next_;
    Node<T>* prev_;
};
```

- Note that we now assume that we have both a `head` pointer, as before and a `tail` pointer variable, which stores the address of the last node in the linked list.
- The tail pointer is not strictly necessary, but it allows immediate access to the end of the list for efficient push-back operations.

11.5 Inserting a Node into the Middle of a Doubly-Linked List

- Suppose we want to insert a new node containing the value 15 following the node containing the value 1. We have a temporary pointer variable, *p*, that stores the address of the node containing the value 1. Here's a picture of the state of affairs:



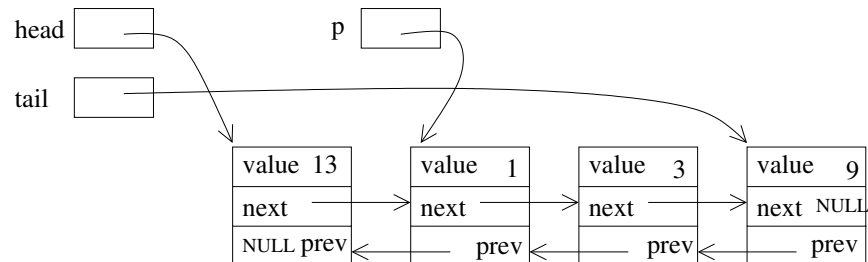
- What must happen? Editing the diagram above...
 - The new node must be created, using another temporary pointer variable to hold its address.
 - Its two pointers must be assigned.
 - Two pointers in the current linked list must be adjusted. Which ones?

Assigning the pointers for the new node **MUST** occur before changing the pointers for the current linked list nodes!

- Exercise:** Write the code as just described. Focus first on the general case: Inserting a new into the middle of a list that already contains at least 2 nodes.

11.6 Removing a Node from the Middle of a Doubly-Linked List

- Now instead of inserting a value, suppose we want to remove the node pointed to by *p* (the node whose address is stored in the pointer variable *p*)



- Two pointers need to change before the node is deleted! All of them can be accessed through the pointer variable *p*.

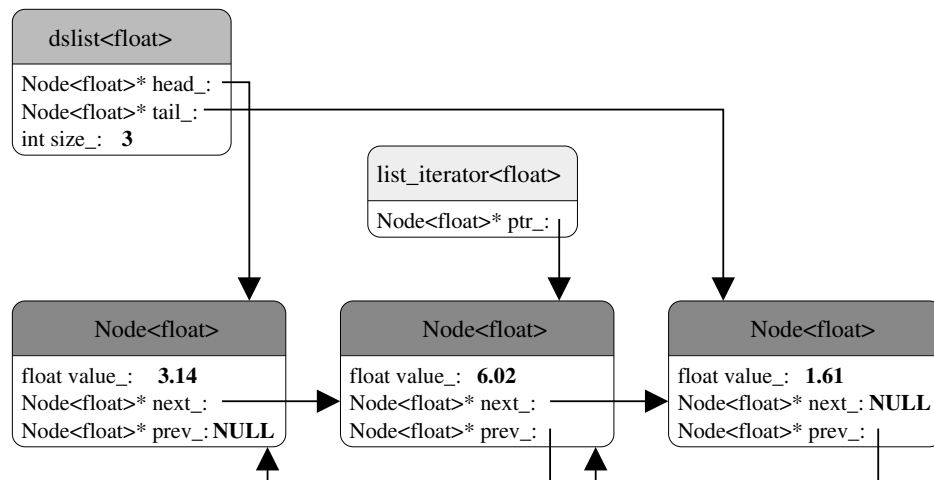
- **Exercise:** Edit the diagram above, and then write this code.

11.7 Special Cases of Remove

- If `p==head` and `p==tail`, the single node in the list must be removed and both the `head` and `tail` pointer variables must be assigned the value `NULL`.
- If `p==head` or `p==tail`, then the pointer adjustment code we just wrote needs to be specialized to removing the first or last node.

11.8 The `dslist` Class — Overview

- We will write a templated class called `dslist` that implements much of the functionality of the `std::list<T>` container and uses a doubly-linked list as its internal, low-level data structure.
- Three classes are involved: the node class, the iterator class, and the `dslist` class itself.
- Below is a basic diagram showing how these three classes are related to each other:



- For each list object created by a program, we have one instance of the `dslist` class, and multiple instances of the `Node`. For each iterator variable (of type `dslist<T>::iterator`) that is used in the program, we create an instance of the `list_iterator` class.

11.9 The `Node` Class

- It is ok to make all members public because individual nodes are never seen outside the list class. (Node objects are not accessible to a user through the public `dslist` interface.)
- Another option to ensure the `Node` member variables stay private would be to nest the entire `Node` class inside of the private section of the `dslist` declaration. We'll see an example of this later in the term.
- Note that the constructors initialize the pointers to `NULL`.

11.10 The Iterator Class — Desired Functionality

- Increment and decrement operators (operations that follow links through pointers).
- Dereferencing to access contents of a node in a list.
- Two comparison operations: `operator==` and `operator!=`.

11.11 The Iterator Class — Implementation

- Unfortunately, unlike our `Vec` class and the STL `vector` class, we can't simply typedef the `iterator` as just a pointer and get the desired functionality for free. The list iterator is a little more complicated.
- We need to define a separate class.
- It stores a pointer to a node in a linked list.
- The iterator constructors initialize the pointer — this constructor will only be called from the `dslist<T>` class member functions.
 - `dslist<T>` is a friend class to allow access to the iterators `ptr_` pointer variable (needed by `dslist<T>` member functions such as `erase` and `insert`).
- `operator*` dereferences the pointer and gives access to the contents of a node. (The user of a `dslist` class is never given full access to a `Node` object!)
- Stepping through the chain of the linked-list is implemented by the increment and decrement operators.
- `operator==` and `operator!=` are defined, but no other comparison operators are allowed.

11.12 The dslist Class — Overview

- Manages the actions of the iterator and node classes.
- Maintains the head and tail pointers and the size of the list. (member variables: `head_`, `tail_`, `size_`)
- Manages the overall structure of the class through member functions.
- Typedef for the `iterator` name.
- Prototypes for member functions, which are equivalent to the `std::list<T>` member functions.
- Some things are missing, most notably `const_iterator` and `reverse_iterator`.

11.13 The dslist class — Implementation Details

- Many short functions are in-lined
- Clearly, it must contain the “big 3”: copy constructor, `operator=`, and destructor. The details of these are realized through the private `copy_list` and `destroy_list` member functions.

11.14 C++ Template Implementation Detail - Using typename

- The use of typedefs within a templated class, for example the `dslist<T>::iterator` can confuse the compiler because it is a *template-parameter dependent name* and is thus ambiguous in some contexts. (Is it a value or is it a type?)
- If you get a strange error during compilation (where the compiler is clearly confused about seemingly clear and logical code), you will need to explicitly let the compiler know that it is a type by putting the `typename` keyword in front of the type. For example, inside of the `operator==` function:

```
typename dslist<T>::iterator left_itr = left.begin();
```

- Don't worry, we'll never test you on where this keyword is needed. Just be prepared that you may need to use it when implementing templated classes that use typedefs.

11.15 Exercises

1. Write `dslist<T>::push_front`
2. Write `dslist<T>::erase`

```

#ifndef dslist_h_
#define dslist_h_
// A simplified implementation of a generic list container class,
// including the iterator, but not the const_iterators. Three
// separate classes are defined: a Node class, an iterator class, and
// the actual list class. The underlying list is doubly-linked, but
// there is no dummy head node and the list is not circular.
#include <cassert>

// -----
// NODE CLASS
template <class T>
class Node {
public:
    Node() : next_(NULL), prev_(NULL) {}
    Node(const T& v) : value_(v), next_(NULL), prev_(NULL) {}

    // REPRESENTATION
    T value_;
    Node<T>* next_;
    Node<T>* prev_;
};

// A "forward declaration" of this class is needed
template <class T> class dslist;

// -----
// LIST ITERATOR
template <class T>
class list_iterator {
public:
    // default constructor, copy constructor, assignment operator, & destructor
    list_iterator() : ptr_(NULL) {}
    list_iterator(Node<T>* p) : ptr_(p) {}
    list_iterator(const list_iterator<T>& old) : ptr_(old.ptr_) {}
    list_iterator<T>& operator=(const list_iterator<T>& old) {
        ptr_ = old.ptr_; return *this;
    }
    ~list_iterator() {}

    // dereferencing operator gives access to the value at the pointer
    T& operator*() { return ptr_->value_; }

    // increment & decrement operators
    list_iterator<T>& operator++() { // pre-increment, e.g., ++iter
        ptr_ = ptr_->next_;
        return *this;
    }
    list_iterator<T>& operator++(int) { // post-increment, e.g., iter++
        list_iterator<T> temp(*this);
        ptr_ = ptr_->next_;
        return temp;
    }
    list_iterator<T>& operator--() { // pre-decrement, e.g., --iter
        ptr_ = ptr_->prev_;
        return *this;
    }
    list_iterator<T>& operator--(int) { // post-decrement, e.g., iter--
        list_iterator<T> temp(*this);
        ptr_ = ptr_->prev_;
        return temp;
    }
};

```

```

// the dslist class needs access to the private ptr_ member variable
friend class dslist<T>;

// Comparisons operators are straightforward
bool operator==(const list_iterator<T>& r) const {
    return ptr_ == r.ptr_; }
bool operator!=(const list_iterator<T>& r) const {
    return ptr_ != r.ptr_; }

private:
    // REPRESENTATION
    Node<T>* ptr_; // ptr to node in the list

};

// -----
// LIST CLASS DECLARATION
// Note that it explicitly maintains the size of the list.
template <class T>
class dslist {
public:
    // default constructor, copy constructor, assignment operator, & destructor
    dslist() : head_(NULL), tail_(NULL), size_(0) {}
    dslist(const dslist<T>& old) { this->copy_list(old); }
    dslist& operator=(const dslist<T>& old);
    ~dslist() { this->destroy_list(); }

    // simple accessors & modifiers
    unsigned int size() const { return size_; }
    bool empty() const { return head_ == NULL; }
    void clear() { this->destroy_list(); }

    // read/write access to contents
    const T& front() const { return head_->value_; }
    T& front() { return head_->value_; }
    const T& back() const { return tail_->value_; }
    T& back() { return tail_->value_; }

    // modify the linked list structure
    void push_front(const T& v);
    void pop_front();
    void push_back(const T& v);
    void pop_back();

    typedef list_iterator<T> iterator;
    iterator erase(iterator itr);
    iterator insert(iterator itr, const T& v);
    iterator begin() { return iterator(head_); }
    iterator end() { return iterator(NULL); }

private:
    // private helper functions
    void copy_list(const dslist<T>& old);
    void destroy_list();

    // REPRESENTATION
    Node<T>* head_;
    Node<T>* tail_;
    unsigned int size_;
};

```

```
// -----  
// LIST CLASS IMPLEMENTATION  
template <class T>  
dslist<T>& dslist<T>::operator= (const dslist<T>& old) {  
    // check for self-assignment  
    if (old != this) {  
        this->destroy_list();  
        this->copy_list(old);  
    }  
    return *this;  
}  
  
template <class T>  
void dslist<T>::push_front(const T& v) {  
  
}  
  
template <class T>  
void dslist<T>::pop_front() {  
  
}  
  
template <class T>  
void dslist<T>::push_back(const T& v) {  
  
}  
  
template <class T>  
void dslist<T>::pop_back() {  
  
}  
  
// do these lists look the same (length & contents)?  
template <class T>  
bool operator== (dslist<T>& left, dslist<T>& right) {  
    if (left.size() != right.size()) return false;  
    typename dslist<T>::iterator left_itr = left.begin();  
    typename dslist<T>::iterator right_itr = right.begin();  
    // walk over both lists, looking for a mismatched value  
    while (left_itr != left.end()) {  
        if (*left_itr != *right_itr) return false;  
        left_itr++; right_itr++;  
    }  
    return true;  
}  
template <class T>  
bool operator!= (dslist<T>& left, dslist<T>& right) { return !(left==right); }  
  
template <class T>  
typename dslist<T>::iterator dslist<T>::erase(iterator itr) {  
  
}  
  
template <class T>  
void dslist<T>::copy_list(const dslist<T>& old) {  
  
}  
  
template <class T>  
void dslist<T>::destroy_list() {  
  
}  
  
#endif
```