CSCI-1200 Data Structures — Fall 2021
Lecture 10 — Doubly-Linked Lists & List Implementation

Review from Lecture 9

- Review of iterators, implementation of iterators in our homemade `Vec` class
- Starting *our own* basic linked list implementation – forward-only, singly-linked
- Implemented: stepping through, push front, push back, and simple insert
- ```
  template <class T> class Node {
    public:
      T value;
      Node* ptr;
  };
  ```
- Push back:

  ```
  template <class T> void push_back( Node<T>* & head, T const& value ) {
    if (head == NULL) {
      head = new Node<T>;
      head->value = value;
      head->ptr = NULL;
    } else {
      push_back(head->next,value);
    }
  }
  ```

- Inserting a Node into a Singly-Linked List - *if p points at node before where you want the insertion*

  ```
    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?

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

10.1 Exercise: 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.

10.2 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 or erase.
- Appending a value at the end requires that we step through the entire list to reach the end.
  ```

10.3 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

10.4 Transition to a Doubly-Linked List Structure

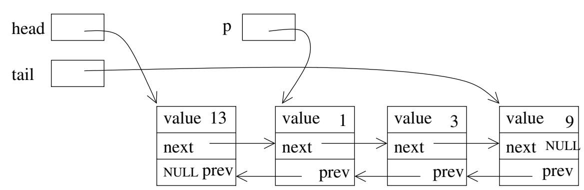
- The revised `Node` class has two pointers, one going "forward" to the successor in the linked list and one going "backward" to the predecessor in the linked list. We will have a `head` pointer to the beginning *and* a `tail` pointer to the end of the list.

```
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_;
};
```

- The tail pointer is not strictly necessary to access the data, but it facilitates efficient push-back operations.
- **Question:** If we have the tail pointer, do we still need the list to be doubly-linked?

10.5 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.



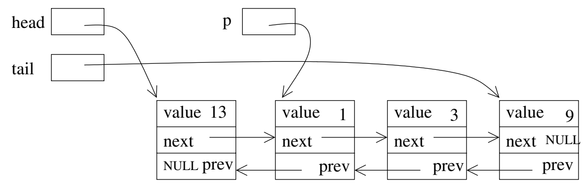
- What must happen? Editing the diagram above...
  - The new node must be created, using another temporary pointer variable to hold its address.
  - Its two pointers must be assigned.
  - Two pointers in the current linked list must be adjusted. Which ones?

  Assigning pointers for the new node MUST occur before changing pointers of the existing 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.

10.6 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 below, and then write this code.

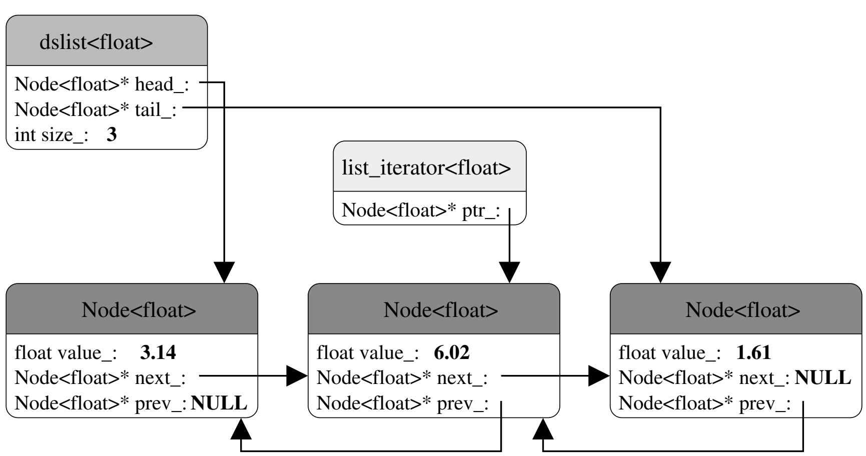


10.7 Special Cases of Remove

- 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.

10.8 The `dslist` Class — Overview

- Our templated class `dslist` 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 (the manager), and multiple instances of the `Node` (one for each value). For each iterator variable (of type `dslist<T>::iterator`) that is used in the program, we create an instance of the `list_iterator` class.

10.9 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.

10.10 The Iterator Class

- 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.
- We have to define a separate class that stores a pointer to a node in a linked list.
- The iterator constructor initializes the pointer. Will only be called from the dslist<T> class member functions.
- Stepping through the chain of the linked-list is implemented by the increment and decrement operators.
- The dereference operator, operator*, gives access to the contents of a node.
(The user of a dslist class is never given full access to a Node object!)
- Two comparison operations: operator== and operator!=. Other comparison (e.g., $<$ or $>$) not allowed.
- 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).

10.11 The dslist Class

- Manages the actions of the iterator and node classes. Interfaces with the user through member functions.
- Maintains the head and tail pointers and the size of the list.
- Typedef for the iterator name.
- Prototypes for member functions, which are equivalent to the std::list<T> member functions.
- As a class managing dynamically-allocated memory, it must implement the "big 3": copy constructor, assignment operator, and destructor. These are implemented with private copy_list and destroy_list helper functions.

10.12 Exercises

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

10.13 Basic Linked Lists Mechanisms: Common Mistakes

Here is a summary of some common mistakes. Review this list when you get stuck on HW or a Test.

- Allocating a new node (using new) to step through the linked list; only a pointer variable is needed.
- Confusing the . and the -> operators. (The compiler will help you – except on a test!)
- Not setting the pointer from the last node to NULL.
- Not considering all special cases: inserting / removing, first or last element, only 1 element, empty list, etc.
- 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 only 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.)

10.14 Unfortunate 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. (Compiler asks: Is "iterator" 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.

```
#ifndef dslist_h_
#define dslist_h_
// A simplified implementation of the STL 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:
  // CONSTRUCTORS: set the pointers to NULL
  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(Node<T>* p=NULL) : ptr_(p) {}
  // NOTE: the implicit compiler definitions of the copy constructor,
  // assignment operator, and destructor are correct for this class

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

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

  // Comparions 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) { copy_list(old); }
  dslist& operator= (const dslist<T>& old);
  ~dslist() { destroy_list(); }

  typedef list_iterator<T> iterator;

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

  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) {
    destroy_list();
    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>
typename dslist<T>::iterator dslist<T>::insert(iterator itr, const T& v) {





}

template <class T>
void dslist<T>::copy_list(const dslist<T>& old) {





}

template <class T>
void dslist<T>::destroy_list() {





}

#endif
```