# CSCI-1200 Data Structures — Spring 2019
# 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

## 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

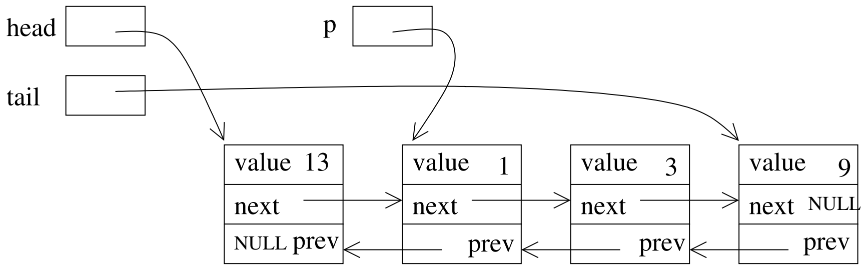
- The revised `Node` class has two pointers, one going "forward" to the successor in the linked list and one going "backward" to the predecessor in the linked list. We will have a `head` pointer to the beginning *and* a `tail` pointer to the end of the list.

```
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:



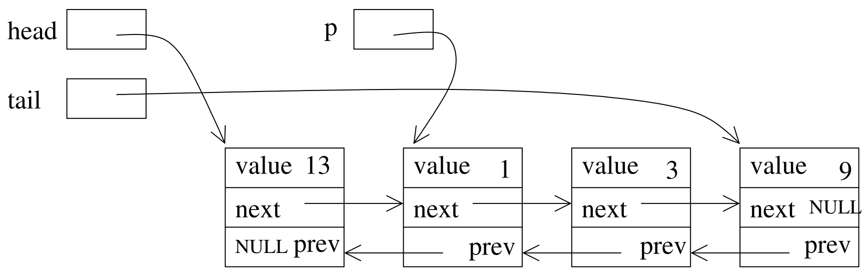
- What must happen? Editing the diagram above...
  - The new node must be created, using another temporary pointer variable to hold its address.
  - Its two pointers must be assigned.
  - Two pointers in the current linked list must be adjusted. Which ones?

  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`)



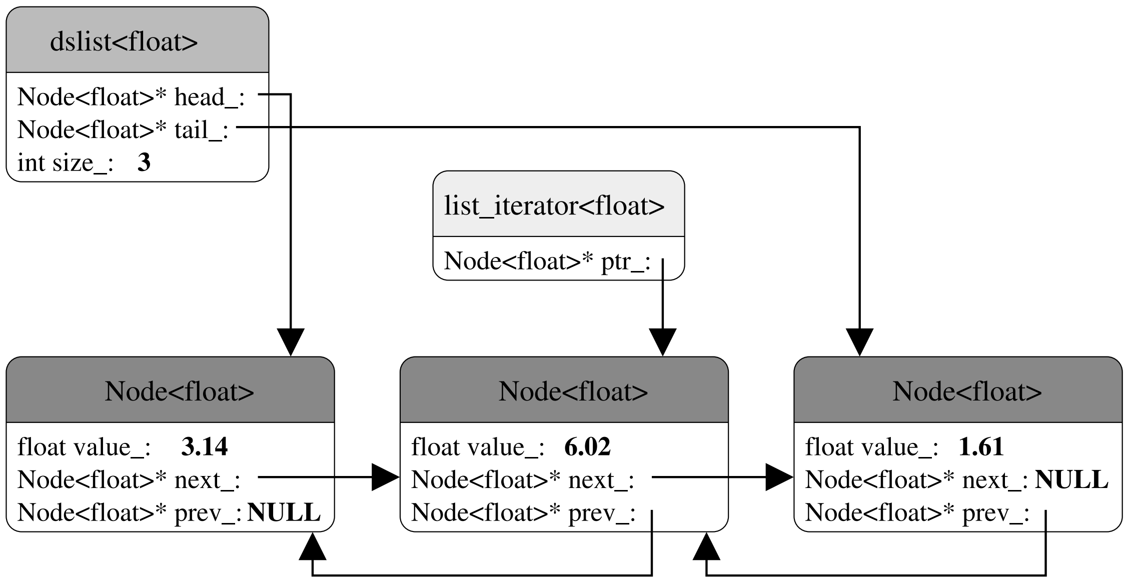
- Two pointers need to change before the node is deleted! All of them can be accessed through the pointer variable `p`.
- **Exercise:** Edit the diagram above, and then write this code.

## 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>;

  // 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) { 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>
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
```