CS 106B, Lecture 19
Linked Lists II
Plan for Today

• Modifying linked lists: Implementing add and delete from a Linked List
• Common Linked Lists gotchas and Linked List tips
• Doubly-Linked Lists
• Linked List as a class
Add to Front

- How would we add to the front of a Linked List?
- Should the front be passed by **reference** or by **value**?
Add To Front

• When **modifying** the list, pass the front ptr by reference
• When simply **iterating** through the list, the front ptr can be passed by value

```cpp
void addToFront(int elem, ListNode * &front) {
    ListNode* newNode = new ListNode(elem, front);
    front = newNode;
}
```
Add to Back

• How would we add to the back of a Linked List?
• Should the front be passed by reference or by value?
void addToBack(ListNode *front, int val) {
    ListNode *tmp = front;
    while (tmp != nullptr) {
        tmp = tmp->next;
    }
    tmp = new ListNode();
    tmp->data = val;
    tmp->next = nullptr;
}
Add to Back: First Try

```c
void addToBack(ListNode *&front, int val) {
    ListNode *tmp = front;
    while (tmp != nullptr) {
        tmp = tmp->next;
    }
    tmp = new ListNode();
    tmp->data = val;
    tmp->next = nullptr;
}
```
void addToBack(ListNode *front, int val) {
    ListNode *tmp = front;
    while (tmp != nullptr) {
        tmp = tmp->next;
    }
    tmp = new ListNode();
    tmp->data = val;
    tmp->next = nullptr;
}
void addToBack(ListNode * &front, int val) {
    ListNode *tmp = front;
    while (tmp != nullptr) {
        tmp = tmp->next;
    }
    tmp = new ListNode();
    tmp->data = val;
    tmp->next = nullptr;
}
void addToBack(ListNode * & front, int val) {
    ListNode * tmp = front;
    while (tmp != nullptr) {
        tmp = tmp->next;
    }
    tmp = new ListNode();
    tmp->data = val;
    tmp->next = nullptr;
}
void addToBack(ListNode *&front, int val) {
    ListNode *tmp = front;
    while (tmp != nullptr) {
        tmp = tmp->next;
    }
    tmp = new ListNode();
    tmp->data = val;
    tmp->next = nullptr;
}
void addToBack(ListNode * &front, int val) {
    ListNode * tmp = front;
    while (tmp != nullptr) {
        tmp = tmp->next;
    }
    tmp = new ListNode();
    tmp->data = val;
    tmp->next = nullptr;
}

// in main after call to addToBack
• When modifying (adding to or removing from) a linked list, we need to be **one node away** from the node we want to impact (**layer of indirection**)  
  – In this case, we need to add the node **after our current node** – how could we do that?
void addToBack(ListNode *&front, int val) {
    ListNode *tmp = front;
    while (tmp->next != nullptr) {
        tmp = tmp->next;
    }
    tmp->next = new ListNode();
    tmp->next->data = val;
    tmp->next->next = nullptr;
}

// in main after call to addToBack
// what if we pass in an empty list?
void addToBack(ListNode * &front, 
    int val) {
    ListNode * tmp = front;
    while (tmp->next != nullptr) {
        tmp = tmp->next;
    }
    tmp->next = new ListNode;
    tmp->next->data = val;
    tmp->next->next = nullptr;
}
// good edge case: empty list
void addToBack(ListNode * &front, int val) {
    ListNode * tmp = front;
    while (tmp->next != nullptr) {
        tmp = tmp->next;
    }
    tmp->next = new ListNode;
    tmp->next->data = val;
    tmp->next->next = nullptr;
}
// in main after call to addToBack
// good edge case: empty list
void addToBack(ListNode * & front, int val) {
    ListNode * tmp = front;
    while (tmp->next != nullptr) {
        tmp = tmp->next;
    }
    tmp->next = new ListNode;
    tmp->next->data = val;
    tmp->next->next = nullptr;
}
// in main after call to addToBack
```cpp
void addToBack(ListNode **front, int val) {
    ListNode *tmp = *front;
    if (*front == nullptr) {
        *front = new ListNode{val, nullptr};
        return;
    }
    while (tmp->next != nullptr) {
        tmp = tmp->next;
    }
    tmp->next = new ListNode;
    tmp->next->data = val;
    tmp->next->next = nullptr;
}
```
Announcements

• Class Survey
  – Thank you to everyone who participated in the class survey.
  – It remains open. So feel free to add any feedback.
  – Currently at ~73%. I will lower it to 80% for a free late day for everyone! You must finish it by the end of day Wednesday
• Doing Well
  – “Very good job explaining concepts, the examples help a lot.”
  – “Being serious in class”

• To Improve Upon
  – “Sometimes he’s super serious when answering questions”
  – “Sometimes he speaks a little too fast but that is only a problem if you watch lecture on 1.5x speed”
  – “He speaks really rapid-fire, then takes a long break...”
  – “Choice of songs”

• One thing
  – “switch the playlist plz!”
  – “Having an assignment due one day after the midterm was a little brutal. ...but having the assignments back earlier than the day the next assignment is due would help us incorporate feedback.”
Announcements

• Playlist Link
  – https://open.spotify.com/user/122062784/playlist/4hlxo8uRQjiOPphQbxtpQ?si=eIKa8qv0Qj-raqwBDtTuvQ
Remove Index

• We've seen how to add to a Linked List
• How would we remove an element from a specific index in the linked list?
  – How do we want to rewire the pointers?
  – Should we pass by value or by reference?
  – What **edge cases** should we consider?
    • Empty list
    • Removing from the front
    • Removing from the back
• Assume for now that the list has an element in that index.
Remove Middle

```
main
  ptr front

Stack

Heap

0x5CBB8C0

int val
  0
ptr next

0x5CBB8CD0

int val
  8
ptr next

0x5CBB8D20

int val
  3
ptr next

main
  ptr front

Stack

Heap

0x5CBB8C0

int val
  0
ptr next

0x5CBB8CD0

int val
  3
ptr next
```
Remove 0

Stack | Heap
--- | ---
main
  ptr front

Heap
0x5CB8C80
  int val
  0
  ptr next

Stack
0x5CB8CD0
  int val
  8
  ptr next

Heap
0x5CB8D20
  int val
  3
  ptr next

Stack | Heap
--- | ---
main
  ptr front

Heap
0x5CB8C80
  int val
  8
  ptr next

Stack
0x5CB8CD0
  int val
  3
  ptr next
void removeIndex(ListNode *front, int index) {
    if (index == 0) {
        front = front->next;
    } else {
        ListNode *tmp = front;
        for (int i = 0; i < index - 1; i++) {
            tmp = tmp->next;
        }
        tmp->next = tmp->next->next;
    }
}
void removeIndex(ListNode *&front, int index) {
    if (index == 0) {
        front = front->next;
    } else {
        ListNode *tmp = front;
        for (int i = 0; i < index - 1; i++) {
            tmp = tmp->next;
        }
        tmp->next = tmp->next->next;
    }
}
Remove Index

- We also need to free memory. How would we do that?
void removeIndex(ListNode *&front, int index) {
    if (index == 0) {
        ListNode *trash = front;
        front = front->next;
        delete trash;
    } else {
        ListNode *tmp = front;
        for (int i = 0; i < index - 1; i++) {
            tmp = tmp->next;
        }
        ListNode *trash = tmp->next;
        tmp->next = tmp->next->next;
        delete trash;
    }
}
void removeIndex(ListNode *front, int index) {
    if (index == 0) {
        ListNode *trash = front;
        front = front->next;
        delete trash;
    } else {
        ListNode *tmp = front;
        for (int i = 0; i < index - 1; i++) {
            tmp = tmp->next;
        }
        ListNode *trash = tmp->next;
        tmp->next = tmp->next->next;
        delete trash;
    }
}
void removeIndex(ListNode *&front, int index) {
    if (index == 0) {
        ListNode *trash = front;
        front = front->next;
        delete trash;
    } else {
        ListNode *tmp = front;
        for (int i = 0; i < index - 1; i++) {
            tmp = tmp->next;
        }
        ListNode *trash = tmp->next;
        tmp->next = tmp->next->next;
        delete trash;
    }
}
void removeIndex(ListNode *&front, int index) {
    if (index == 0) {
        ListNode *trash = front;
        front = front->next;
        delete trash;
    } else {
        ListNode *tmp = front;
        for (int i = 0; i < index - 1; i++) {
            tmp = tmp->next;
        }
        ListNode *trash = tmp->next;
        tmp->next = tmp->next->next;
        delete trash;
    }
}
void removeIndex(ListNode *&front, int index) {
    if (index == 0) {
        ListNode *trash = front;
        front = front->next;
        delete trash;
    } else {
        ListNode *tmp = front;
        for (int i = 0; i < index - 1; i++) {
            tmp = tmp->next;
        }
        ListNode *trash = tmp->next;
        tmp->next = tmp->next->next;
        delete trash;
    }
}
Linked List as a Class

• What instance variables (fields) do we need?
• What should the constructor do? The destructor?
• Idea: instead of passing in front explicitly, store it as an instance variable!
// Represents a linked list of integers.
class LinkedIntList {
public:
    LinkedIntList();
    ~LinkedIntList();
    void addBack(int value);
    void addFront(int value);
    void deleteList();
    void print() const;
    bool isEmpty() const;
    ...

private:
    ListNode* front; // nullptr if empty
};
// (partial)
#include "LinkedIntList.h"
LinkedIntList::LinkedIntList() {
    front = nullptr;
}

bool LinkedIntList::isEmpty() {
    return front == nullptr;
}

void LinkedIntList::addFront(int value) {
    ListNode* newNode = new ListNode(value);
    newNode->next = front;
    front = newNode;
}

...
Delete Linked List

• How do we delete our linked list?
void deleteList(ListNode * & front) {
    if (front == nullptr) {
        return;
    }
    deleteList(front->next);
    delete front;
}
Linked List: Pros and Cons

• Pros:
  – Fast to add/remove near the front of the list
    • Great for queues, especially if we keep a pointer to the end of the LL
  – Can merge or concatenate two linked lists without allocating any more memory
  – Only uses the memory to store the number of elements in the list

• Cons:
  – Slow to "index" into the list
  – Slow to add/remove in the middle or near the end of the list
  – Can only iterate one way
Doubly-Linked List

• Have each node point to the next node in the list and the previous node in the list
• Generally store pointer to the front and back
• Advantages:
  – easy to add to the front and the back of the list
  – don't need a level of indirection for adding/removing nodes

struct DoublyListNode {
  int data;
  ListNode *prev;
  ListNode *next;
};
Final Thoughts on LL

• Every element in a Linked List is stored in its own block, which we call a ListNode
  – Can only access an element by visiting every element before it
• When **modifying** the list, pass the front ListNode by reference
• When simply **iterating** through the list, the front ListNode can be passed by value
• **Edge cases:** Test your code with a Linked List of size 0, 1, 2, and 3, and with operations on the beginning, middle, and end
• When in doubt, draw out a memory diagram
• **Practice safe pointers:** always check for null before dereferencing!