CS 106B, Lecture 17
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

Recap

- 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
  - Do you see why?

Add to Back

- Yesterday, we talked about how to add to the front of a linked list
- How would we add to the back of a Linked List?
- Should the front be passed by **reference** or by **value**?

Add to Back: First Try

```
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

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void addToBack(ListNode *&front,
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    ListNode *tmp = front;
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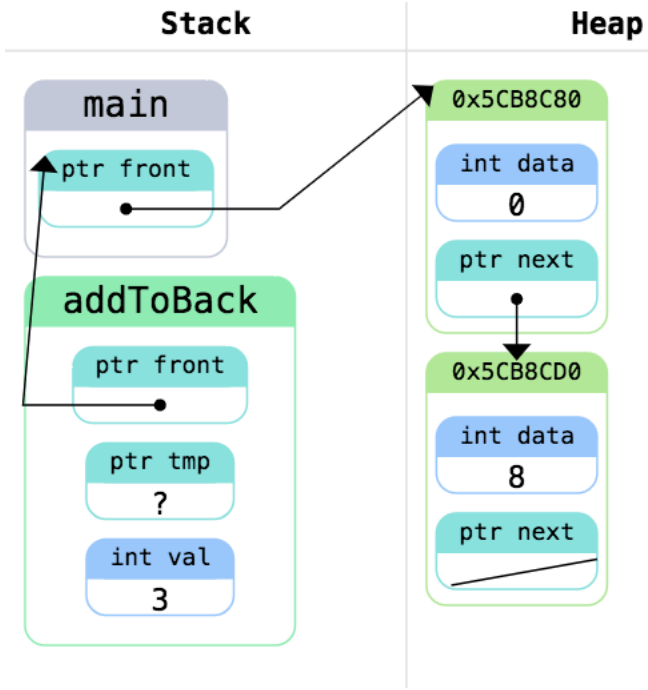

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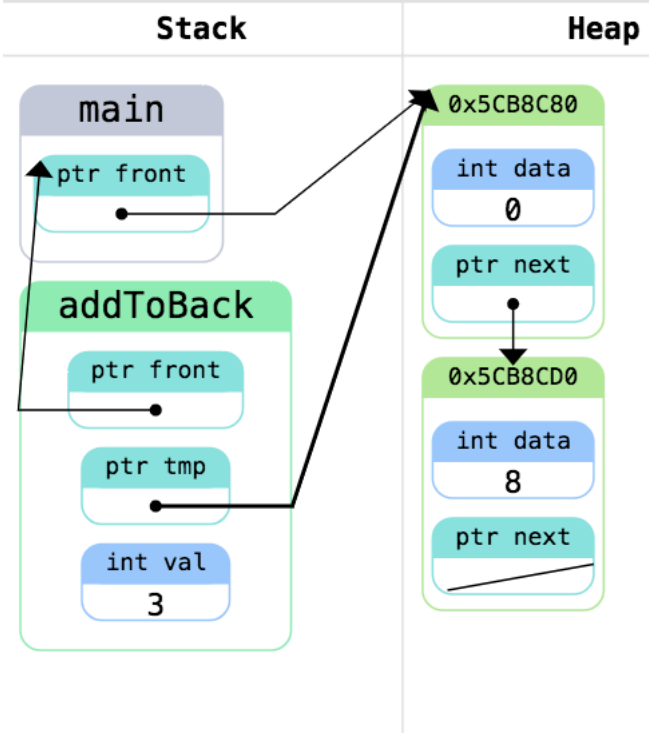

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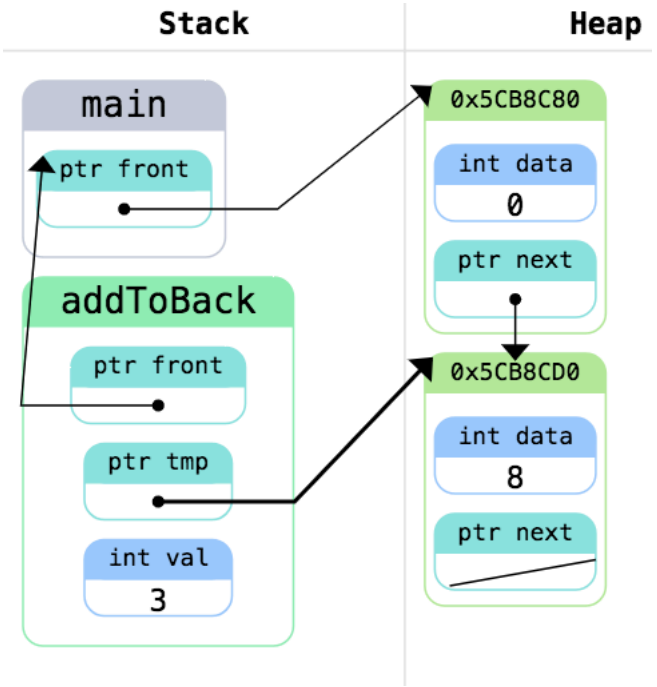

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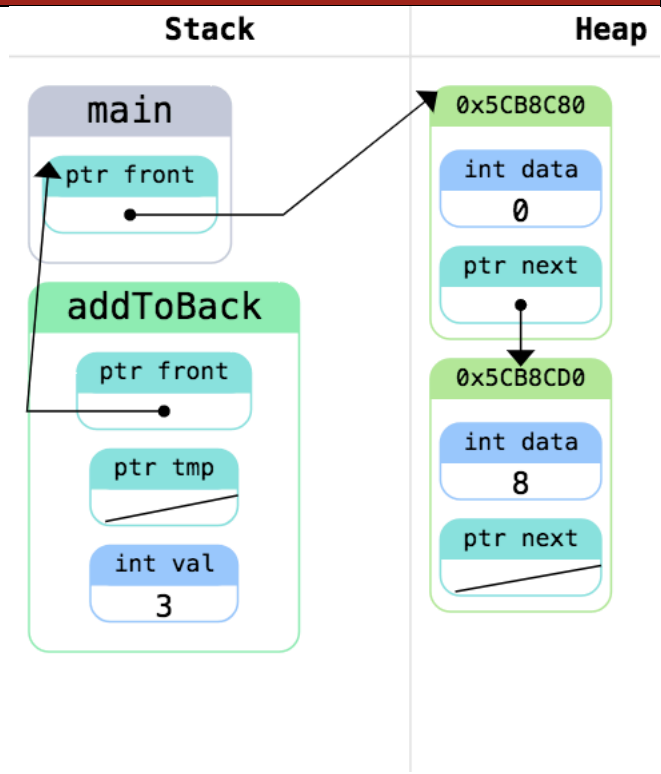
}
```



Add to Back: First Try

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```

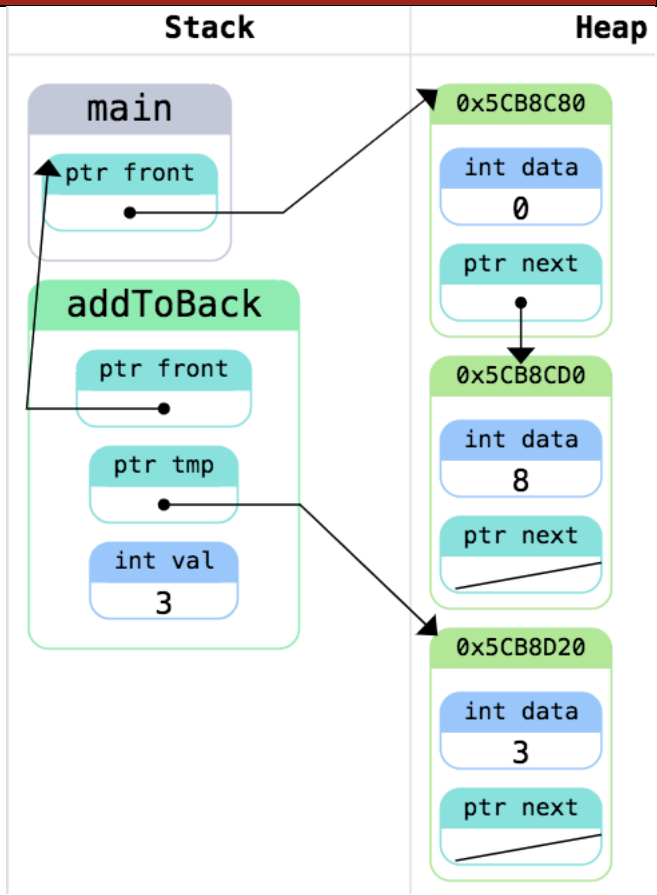

Add to Back: First Try

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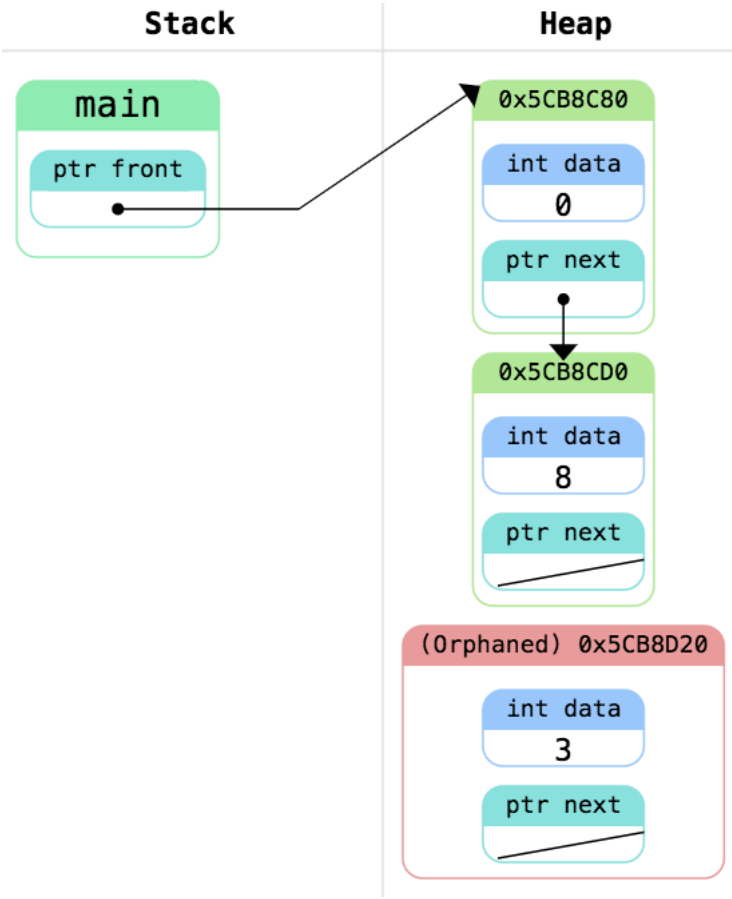
               int val) {
    ListNode *tmp = front;
    while (tmp != nullptr) {
        tmp = tmp->next;
    }
    tmp = new ListNode;
    tmp->data = val;
    tmp->next = nullptr;
}
// in main after call to addToBack
```

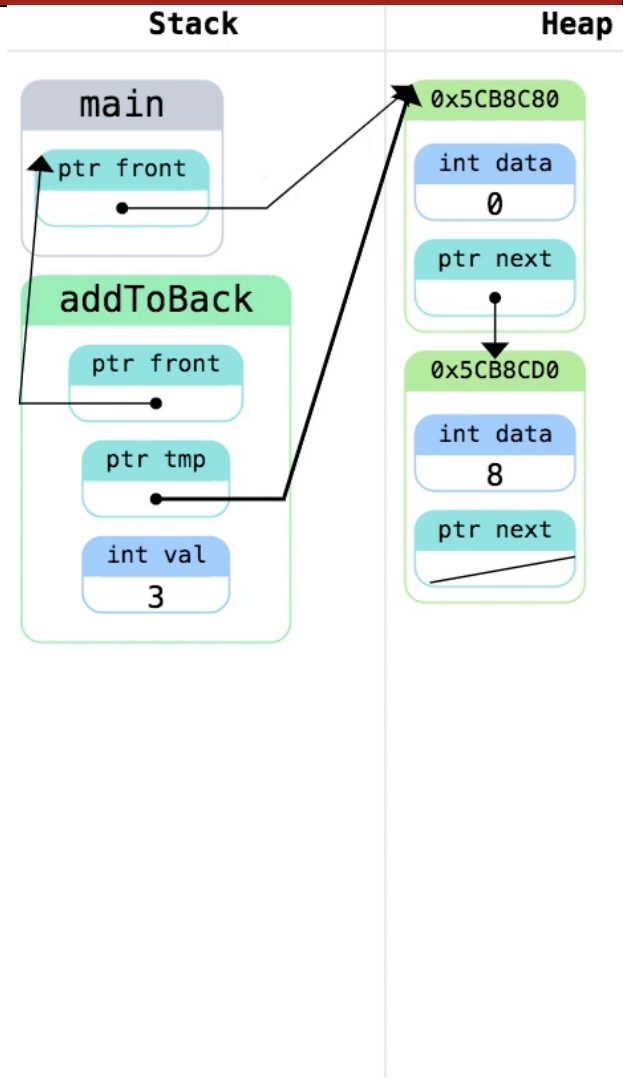


Add to Back: Key Point

- 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?

Add to Back: Second Try

```
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
```

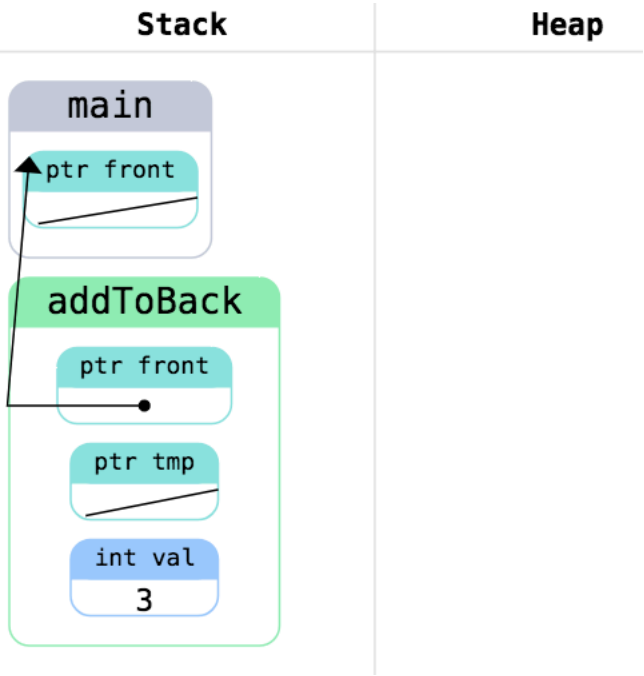


Add to Back: Second Try

```
// 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;
}
```

Add to Back: Second Try

```
// 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
```



Add to Back: Second Try

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// good edge case: empty list
void addToBack(ListNode *&front,
               int val) {
    ListNode *tmp = front;
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        tmp = tmp->next;
    }
    tmp->next = new ListNode;
    tmp->next->data = val;
    tmp->next->next = nullptr;
}
// in main after call to addToBack
```
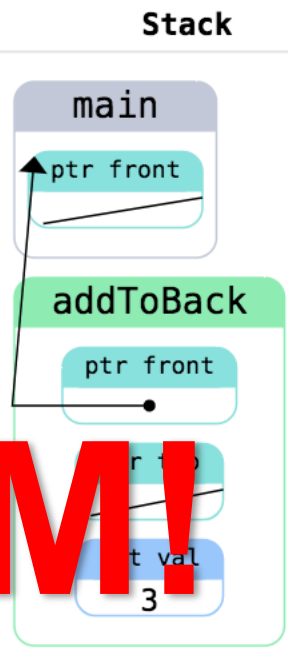

KABOOM!



Add to Back: Solution

```
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;
}
```

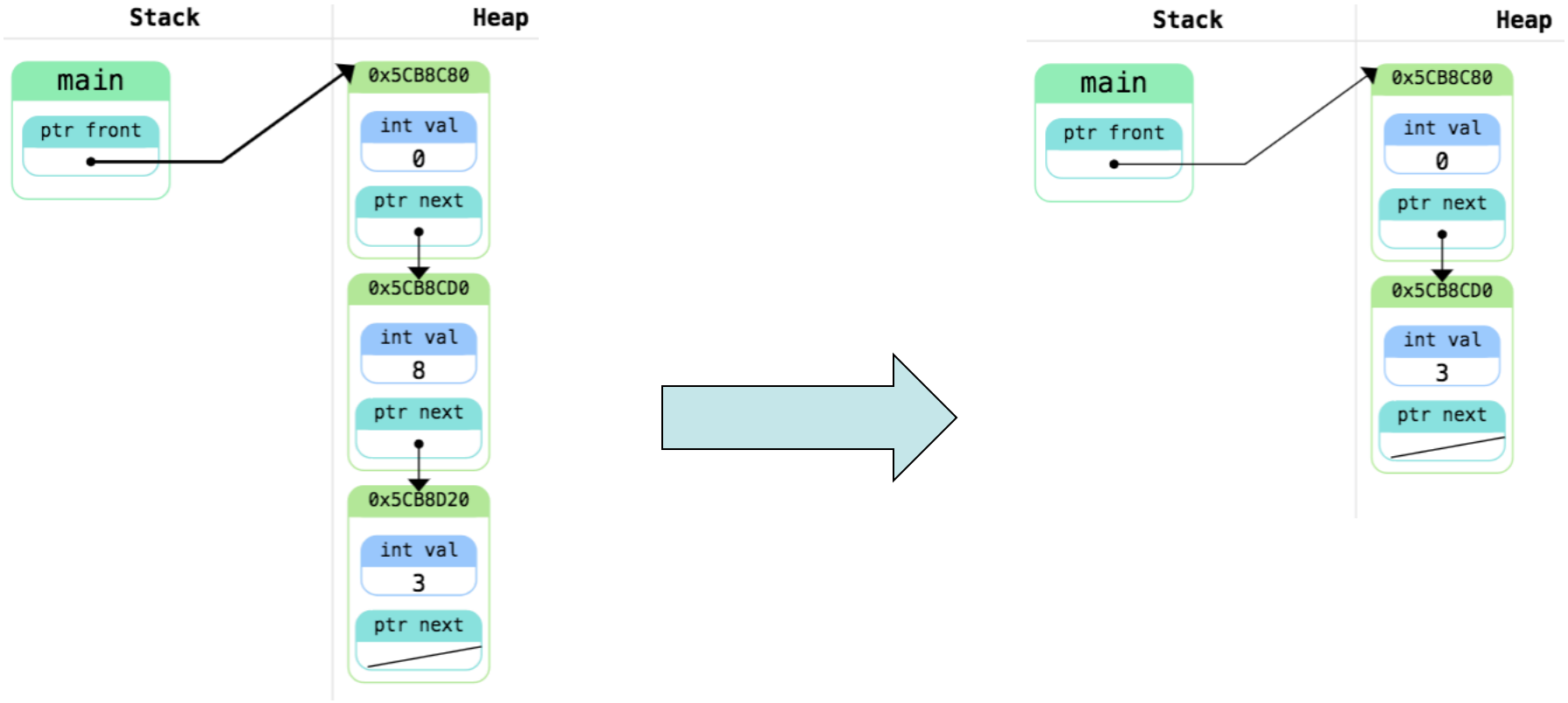
Announcements

- Assignment 4 is due on **Thursday** – please finish it before then
- You will get assignment 3 feedback on **Wednesday** (tomorrow)
- Please give feedback (if you have the next 30 minutes free): cs198.stanford.edu
- Exam logistics
  - Midterm review session **today**, from 7:00-8:30PM, in Gates B01, led by SL Peter
  - Midterm is on Wednesday (tomorrow), July 25, from 7:00-9:00PM in Hewlett 200
  - Complete assignment 4 before the midterm – backtracking will be tested

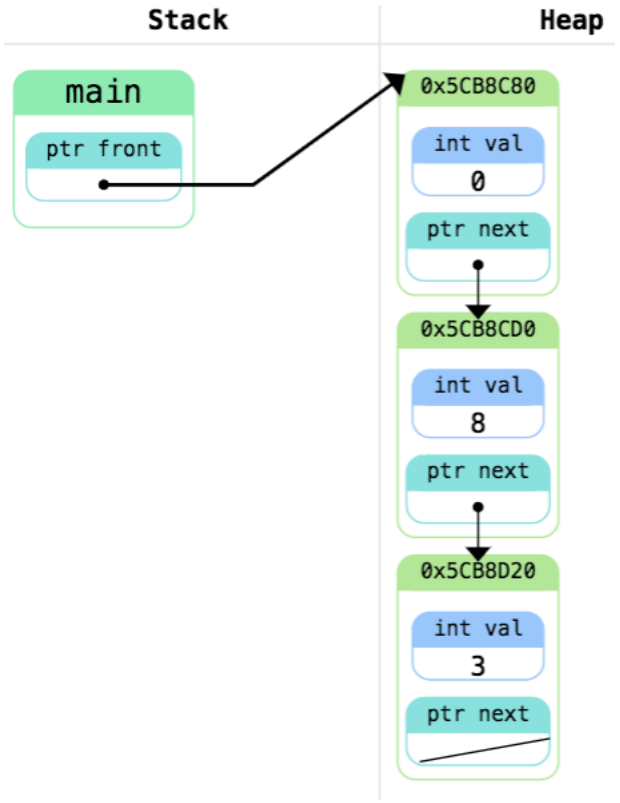
Remove Index

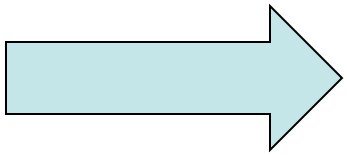
- We've seen how to add to a Linked List
- How would we remove an element from a specific index in the linked list?
  - How do we want to rewire the pointers?
  - Do we need a layer of indirection?
  - Should we pass by value or by reference?
  - What **edge cases** should we consider?
    - Empty list
    - Removing from the front
    - Removing from the back
- Assume for now that the list has an element in that index.
  - Thought exercise: how would you modify the solution if to handle shorter lists?

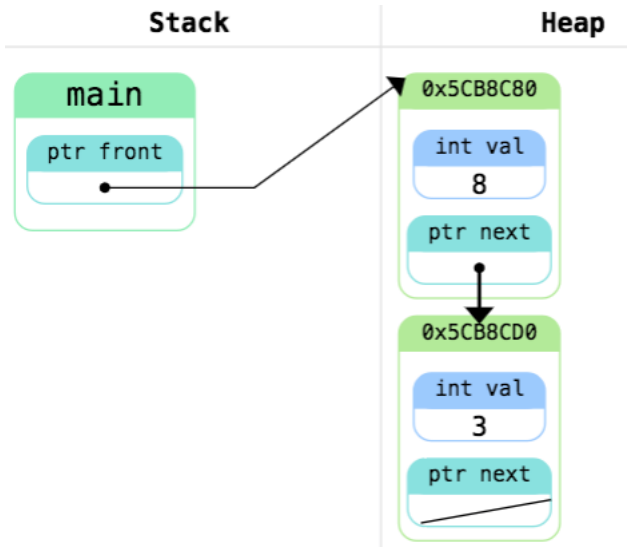
Remove Middle



Remove 0


Stack
Heap
main
ptr front
0x5CB8C80
int val
0
ptr next
0x5CB8CD0
int val
8
ptr next
0x5CB8D20
int val
3
ptr next




Stack
Heap
main
ptr front
0x5CB8C80
int val
8
ptr next
0x5CB8CD0
int val
3
ptr next

Remove Index: First Try

```
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: First Try

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  }
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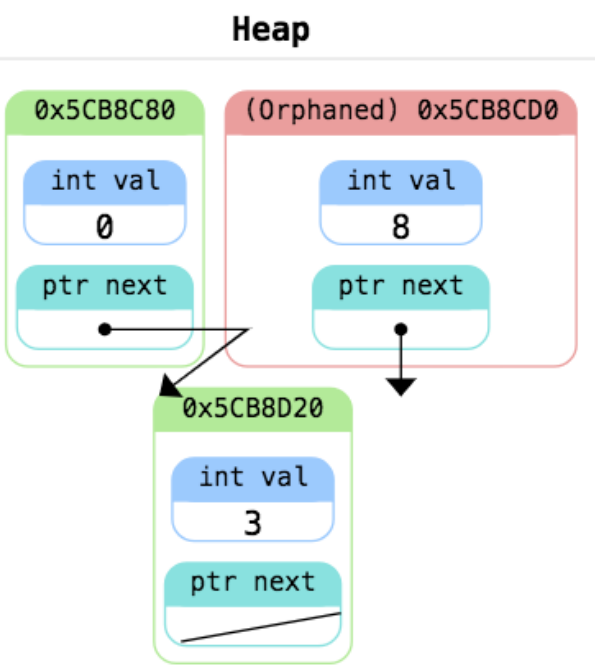
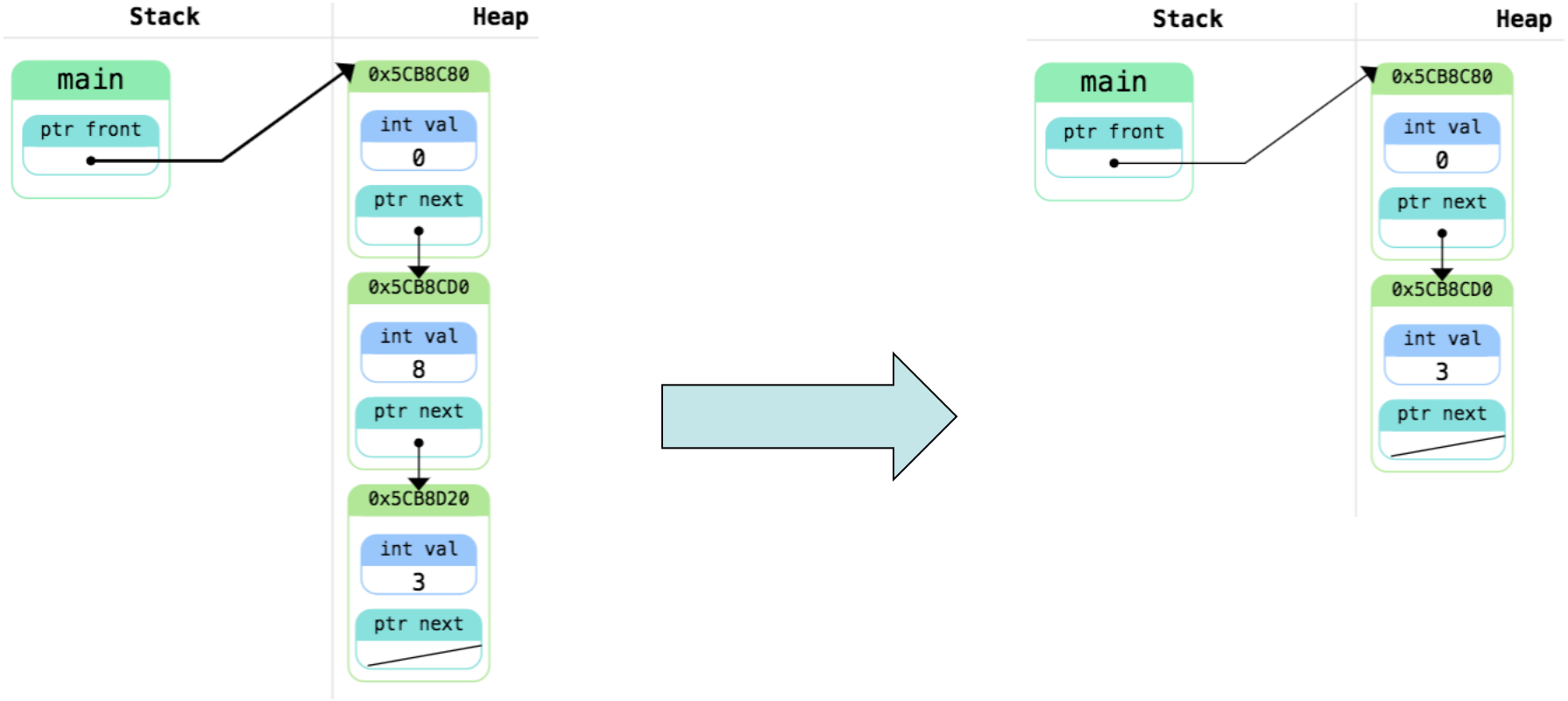


Remove Index

- We also need to free memory. How would we do that?



Remove Index: Solution

```
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;
  }
}
```

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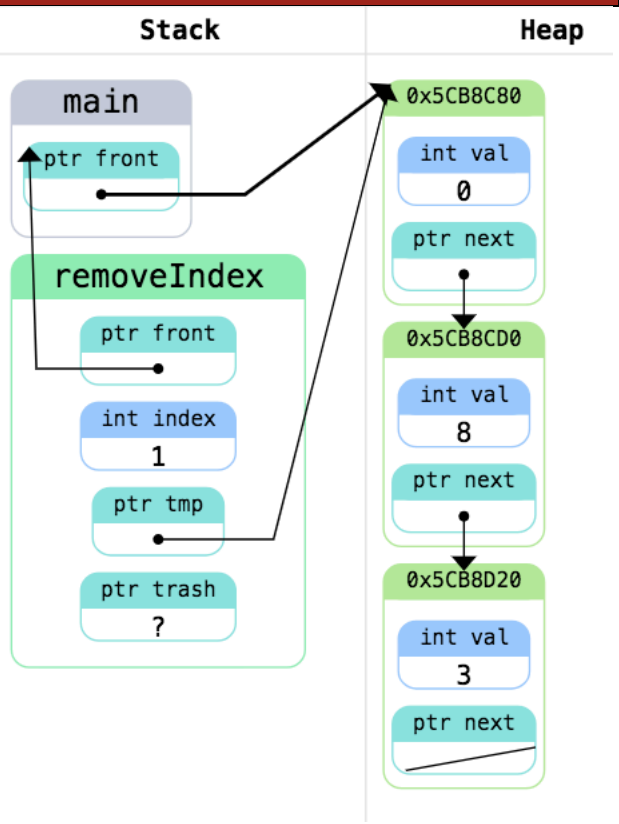
    ListNode *tmp = front;
    for (int i = 0; i < index - 1; i++) {
      tmp = tmp->next;
    }
    ListNode *trash = tmp->next;
    tmp->next = tmp->next->next;
    delete trash;
  }
}
```



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    for (int i = 0; i < index - 1; i++) {
      tmp = tmp->next;
    }
    ListNode *trash = tmp->next;
    tmp->next = tmp->next->next;
    delete trash;
  }
}
```

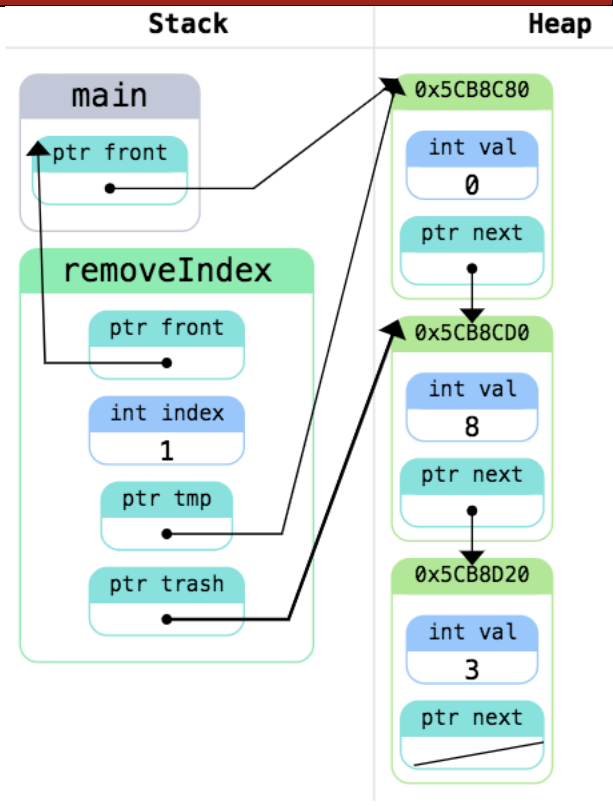

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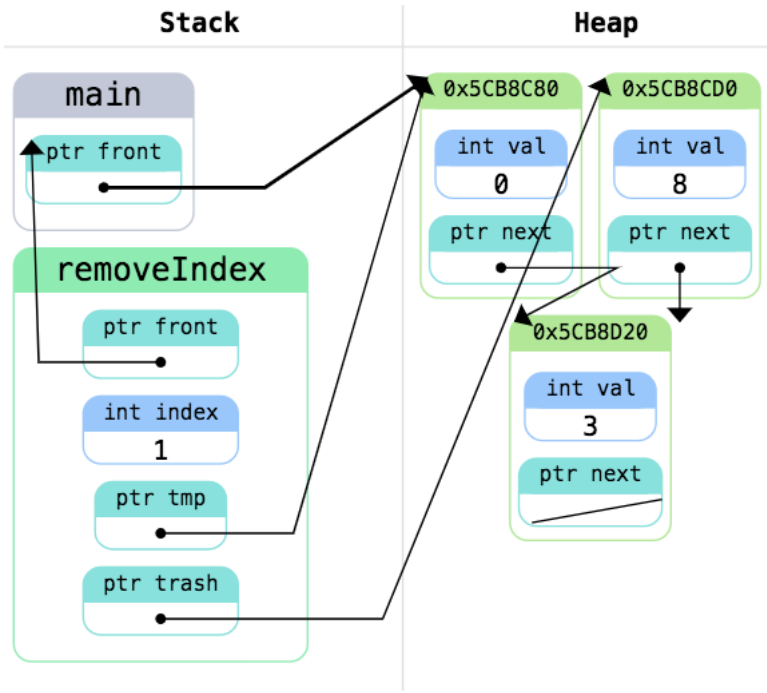
    delete trash;
  } else {
    ListNode *tmp = front;
    for (int i = 0; i < index - 1; i++) {
      tmp = tmp->next;
    }
    ListNode *trash = tmp->next;
    tmp->next = tmp->next->next;
    delete trash;
  }
}
```



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    for (int i = 0; i < index - 1; i++) {
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    tmp->next = tmp->next->next;
    delete trash;
  }
}
```
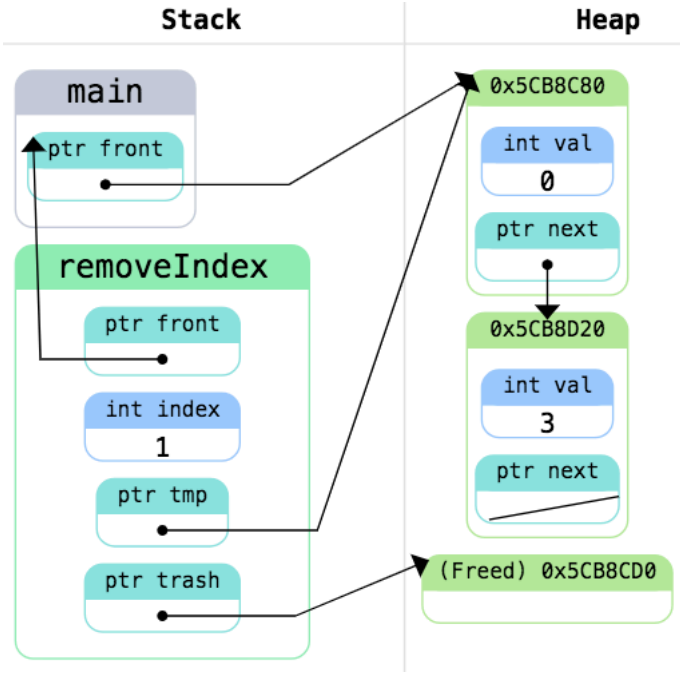



Linked List as a Class

- 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!

LinkedIntList.h

```
// 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
};
```

LinkedIntList.cpp

```
// (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;
}
...
```

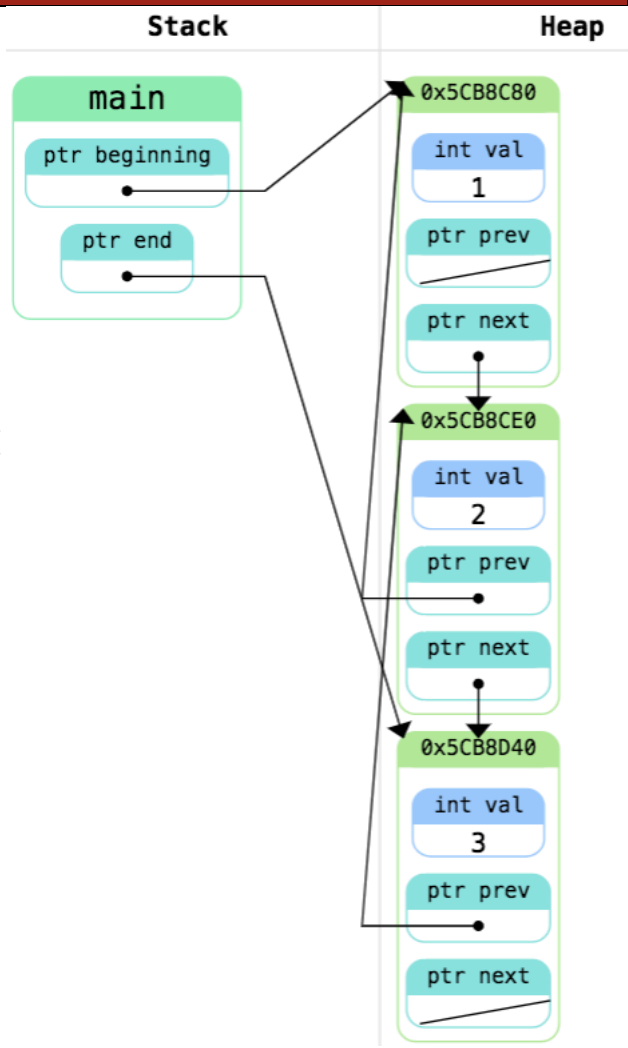
Linked List: Pros and Cons

- 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
    - Thought experiment: how?
  - 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
- You'll see these on your next homework

```
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 (we've had a lot of these in class!)
- **Practice safe pointers: always check for null before dereferencing!**