CS 106X, Lecture 16
Linked Lists Summary

reading:

Programming Abstractions in C++, Chapters 11-12, 14.1-14.2

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Based on slides created by Keith Schwarz, Julie Zelenski, Jerry Cain, Eric Roberts, Mehran Sahami, Stuart Reges, Cynthia Lee, Marty Stepp, Ashley Taylor and others.

Personal Note on Linked List

/*Summary:
* Use pointer to represent a list: **ListNode* front;**
* Store **pointer in stack**; Store **list in heap: new ListNode(value);**
* When iterating a list: make a **copy of front**, i.e ListNode* current = front, use curr to iterate the list. Nodes are like ballons, we need a string-namely front- to tie them up.
* For functions that change the list: **use reference to pointer: ListPointer*& name;**
* Iterate over the list: while (curr) {} go all the way down
* Operation over list: **James Bond Analogy**: curr goes to the **node BEFORE the node of interest!**
* Consider special case when index = 0 since there is no carriage you Bond can stand on it.
* Also consider: empty list
* Remove element: clean up memory
* Removal Mode: ListNode* trash = object;
* Operations;
* delete trash;
*/
* Meaning of ->:Movement: a->next means follow the pointer a and walk to the object that it points to, and use dot to find attribute.

核心总结:

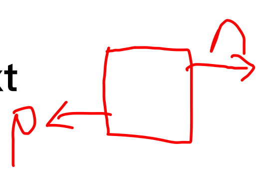
1. 链表相关操作设计通法：仔细的do an instance yourself. write what you have done in detail

2. 操作函数传参数:node* or node*&? 更改指针所指对象node用*，改变指针本身指的位置用*&

3. 习惯delete完一个指针之后要把指针设置成nullptr，不要出现dangling ptr

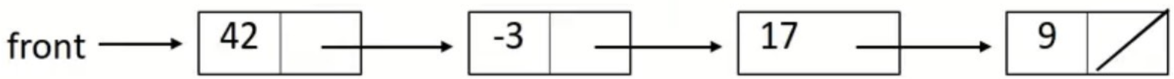
5. 存链表：stack里面存个front指针，节点都存在heap里面

6. 双向链表的node的prev和next
一般双向链表还有一个end指针



Linked data structures

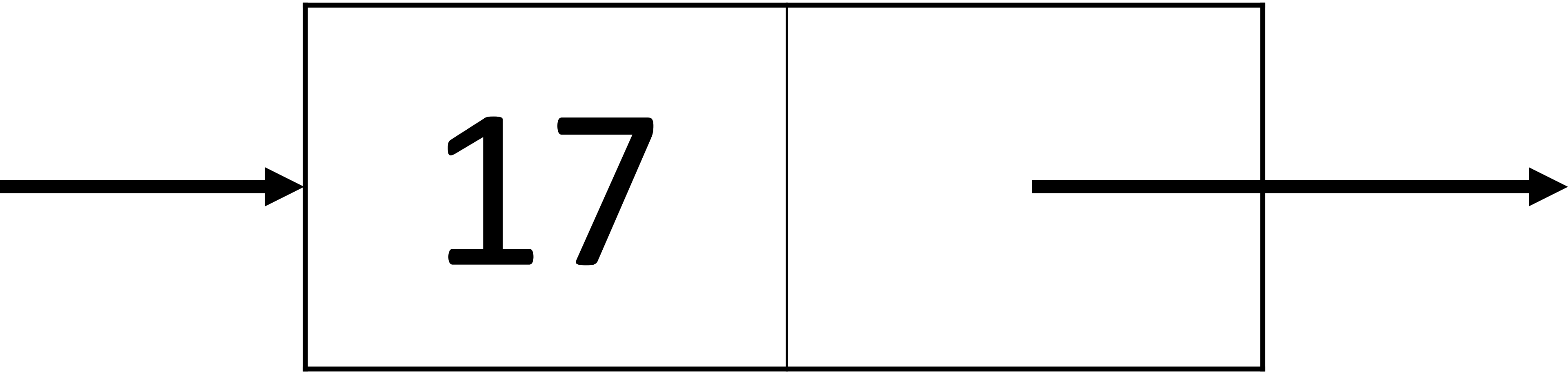
- Some collections store their data using **linked node** structures.
  - Each node stores one element and a link to another node(s).
  - examples: `Set`, `Map`, `LinkedList`



- *Pros:* fast to add/remove at any point; no shifting, no resizing.
- *Cons:* slow to access certain parts of the list.

- This week we will learn how to create a *linked list*.
- To do linked lists, we must understand some new C++ concepts.
  - To represent nodes, we need to know about ***structs***.
  - To link nodes to each other, we must learn ***pointers***.

Nodes

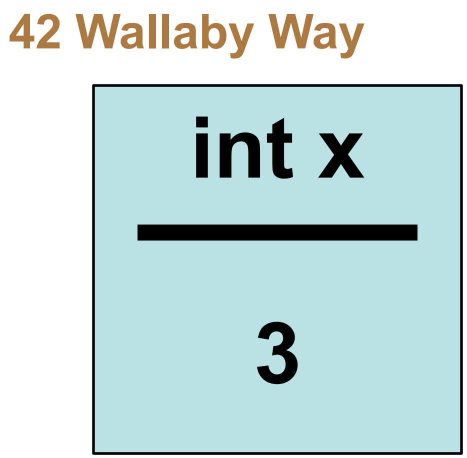



```
struct ListNode {
    int data;
    ListNode *next;
};
```

Pointers

A pointer is a variable type that stores a memory address.

Addresses




```
int x = 3;
int *xAddress = &x;
```

The **&** operator is the **address of** operator. It gets the address of a variable in memory.

Addresses

```
int x = 3;
int *xAddress = &x;
```

`xAddress` is a **pointer** to **`x`**. It is a variable that "points to" another variable, meaning that it stores the address of another variable.

Addresses

```
int x = 3;
int *xAddress = &x;
```

`x` is the **pointee** of **`xAddress`**. It is being pointed to by **`xAddress`**.

Dereferencing

```
int x = 3;
int *xAddress = &x;

*xAddress = 5;
```

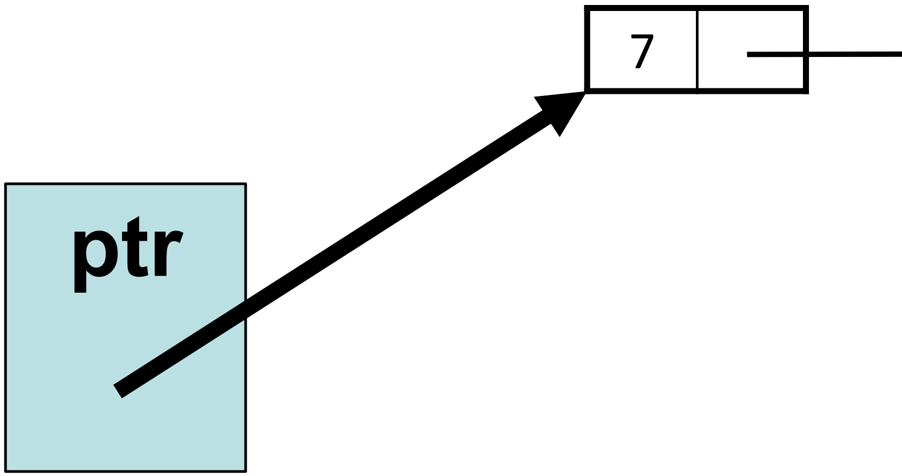
The `*` operator is the **dereference** operator. It tells C++ to *go to the variable* at the address stored in that pointer.

Dereference Classes/Structs

```
ListNode n = ...
ListNode *ptr = &n;

ptr->data = 7;
```

The -> operator is shorthand for dereferencing a pointer and then accessing a member.

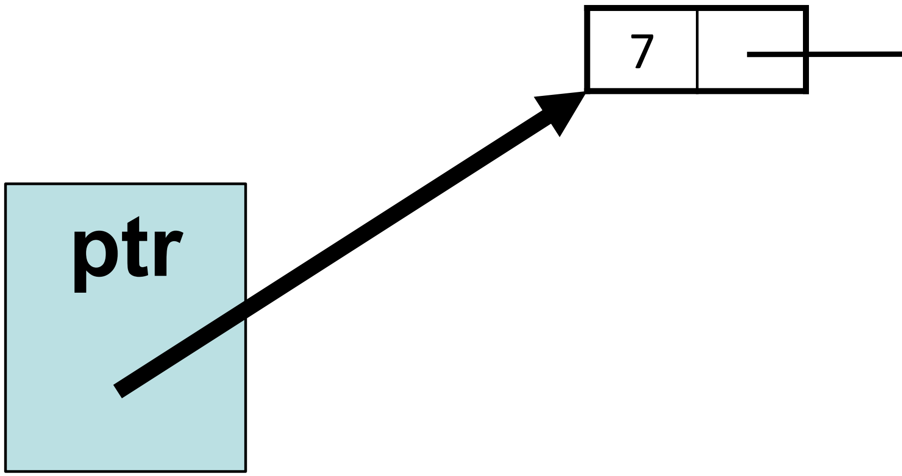


Dereference Classes/Structs

```
ListNode n = ...
ListNode *ptr = &n;

(*ptr).data = 7;
```

The `->` operator is shorthand for dereferencing a pointer and then accessing a member.



nullptr

int *xAddress

nullptr

```
int *xAddress = nullptr;
```

`nullptr` is a special value that represents “no address”.

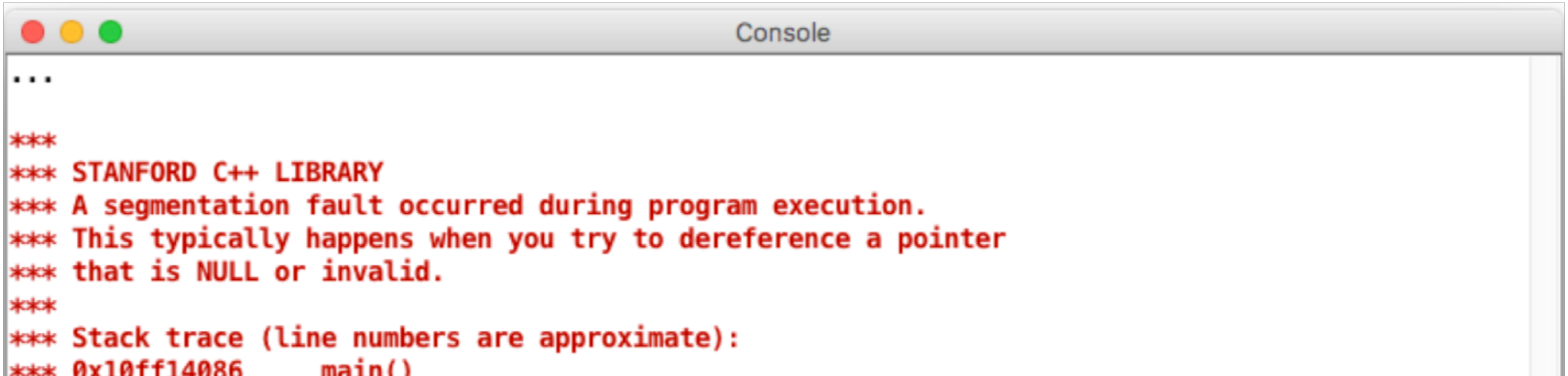
Dereferencing nullptr

int *xAddress

nullptr

`int *xAddress = nullptr;`

`cout <<` ~~`*xAddress`~~ `<< endl;`

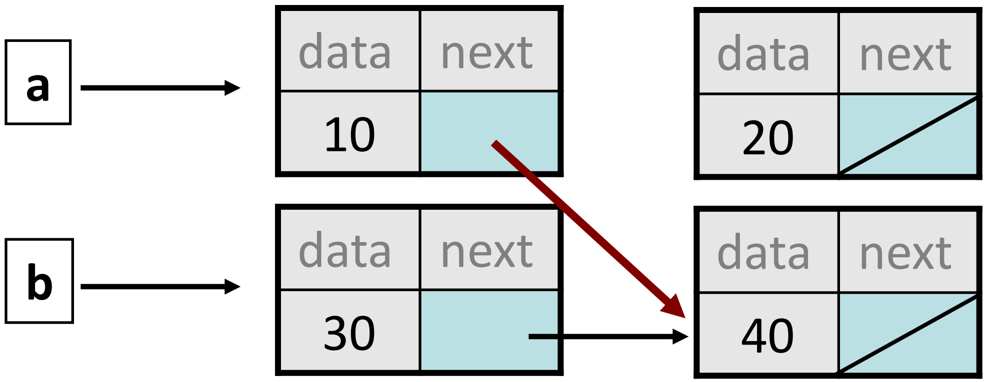


Garbage Pointers


```
int *xAddress; // initially garbage ❌
cout << xAddress << endl; // ???
cout << *xAddress << endl; // likely crash!


// always initialize pointers!
// (even just to nullptr)
int *xAddress = nullptr;  // ✅
```

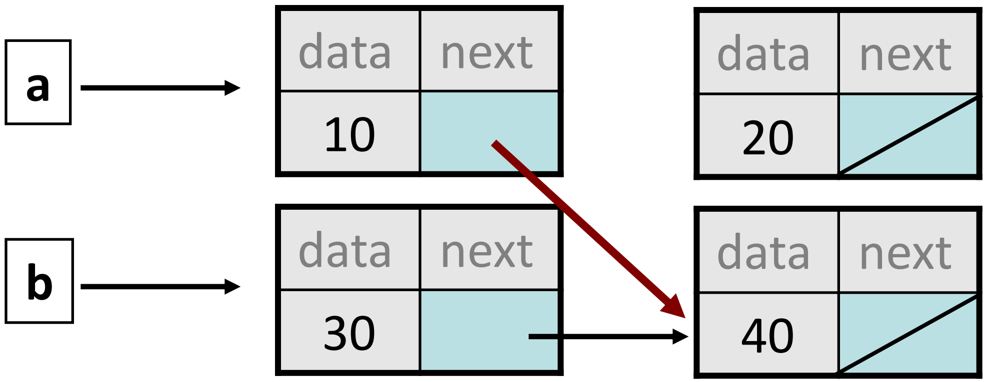
Reassigning Pointers




```
a->next = b->next;
```

Setting two pointers equal to each other means they both *point to the same place*.

Reassigning Pointers




```
ListNode secondNode = {40, nullptr};
```

~~`a->next = secondNode;`~~

Tip: the types on the left- and right-hand sides must always match!

Pointer to struct/obj

IMPORTANT!

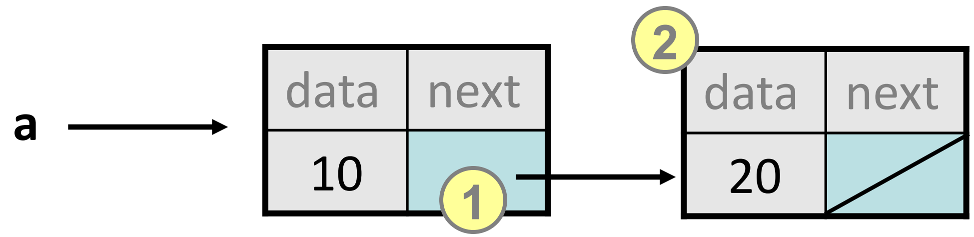
`variable = value;`

a *variable* (left side of =) is an arrow *(the base of an arrow)*

a *value* (right side of =) is an object *(a box; what an arrow points at)*

Assignment between pointers are different from assignment between varables.
Understanding of pointer: an arrow points to "pointee"

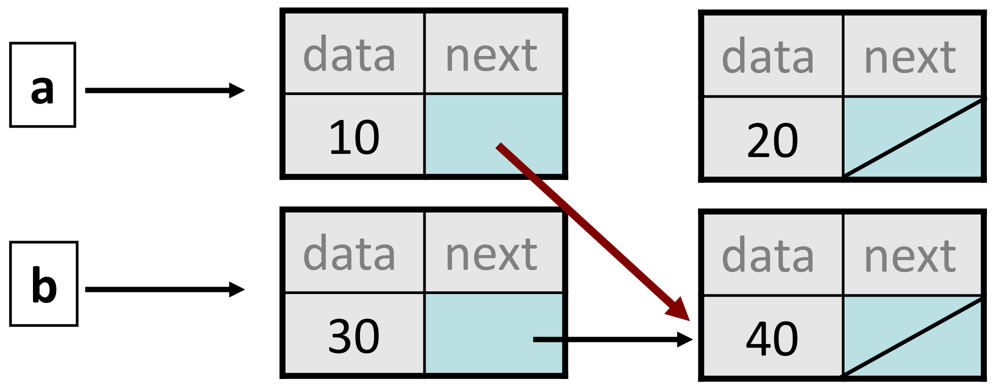
- For the list at right:



`a->next = p;` **tell the next arrow points to the same place where p points.**
means to adjust 1 to point where ***p*** points

`p = a->next;`
means to make ***p*** point where `a->next` points, which is at 2

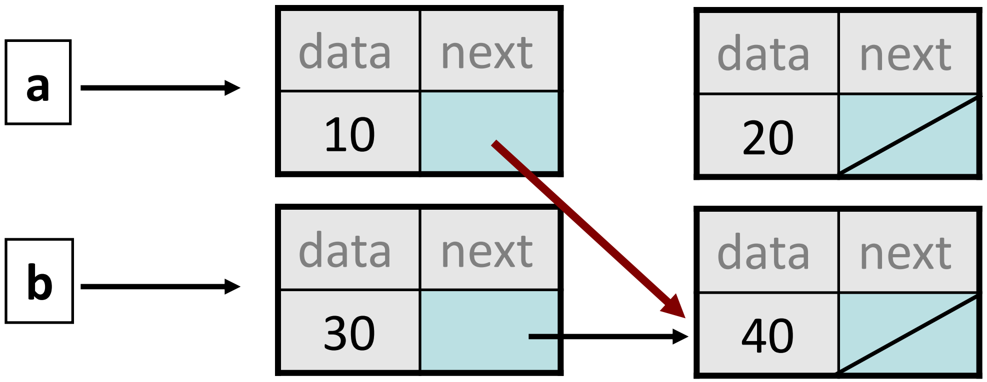
Reassigning Pointers




```
a->next = b->next;
```

Setting two pointers equal to each other means they both *point to the same place*.

Reassigning Pointers

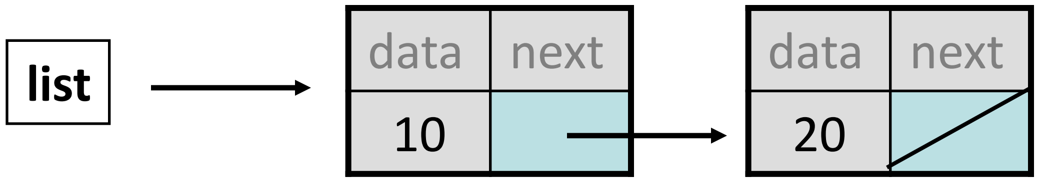


~~`a->next = firstNode;`~~

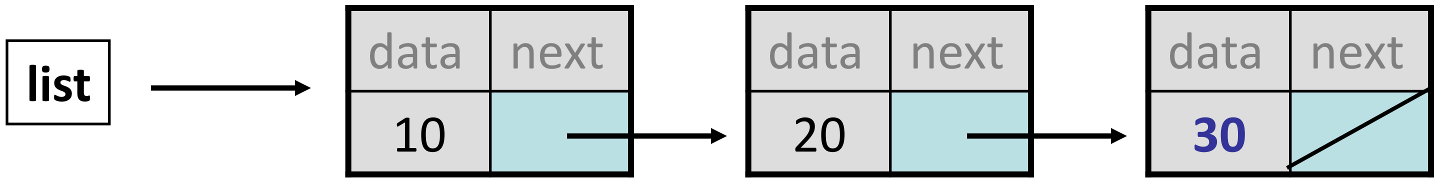
Tip: the types on the left- and right-hand sides must always match!

Linked node problem 1

- Which statement turns this picture:



- Into this?




```
ListNode node = {30, nullptr};
```

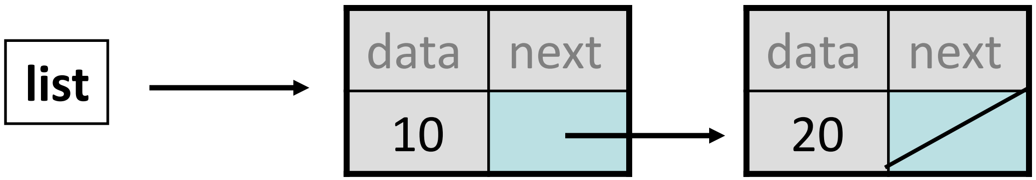
A. `list->next = node;`

B. `list->next->next = &node;`

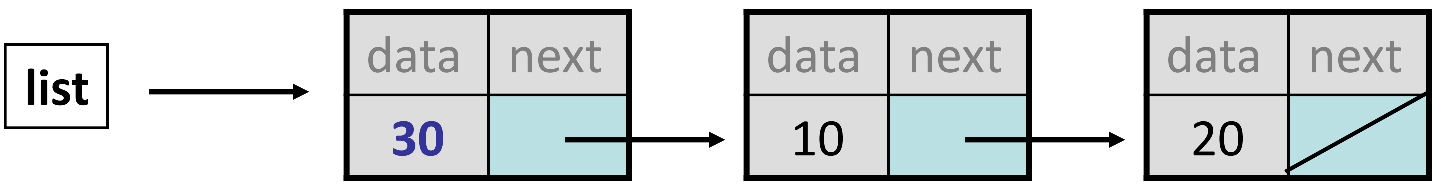
C. `list->next->next->next = node;`

Linked node problem 2

- Which statements turn this picture:



- Into this?




```
ListNode temp = {30, nullptr};
```

A. `temp.next = list;` `list = &temp;`

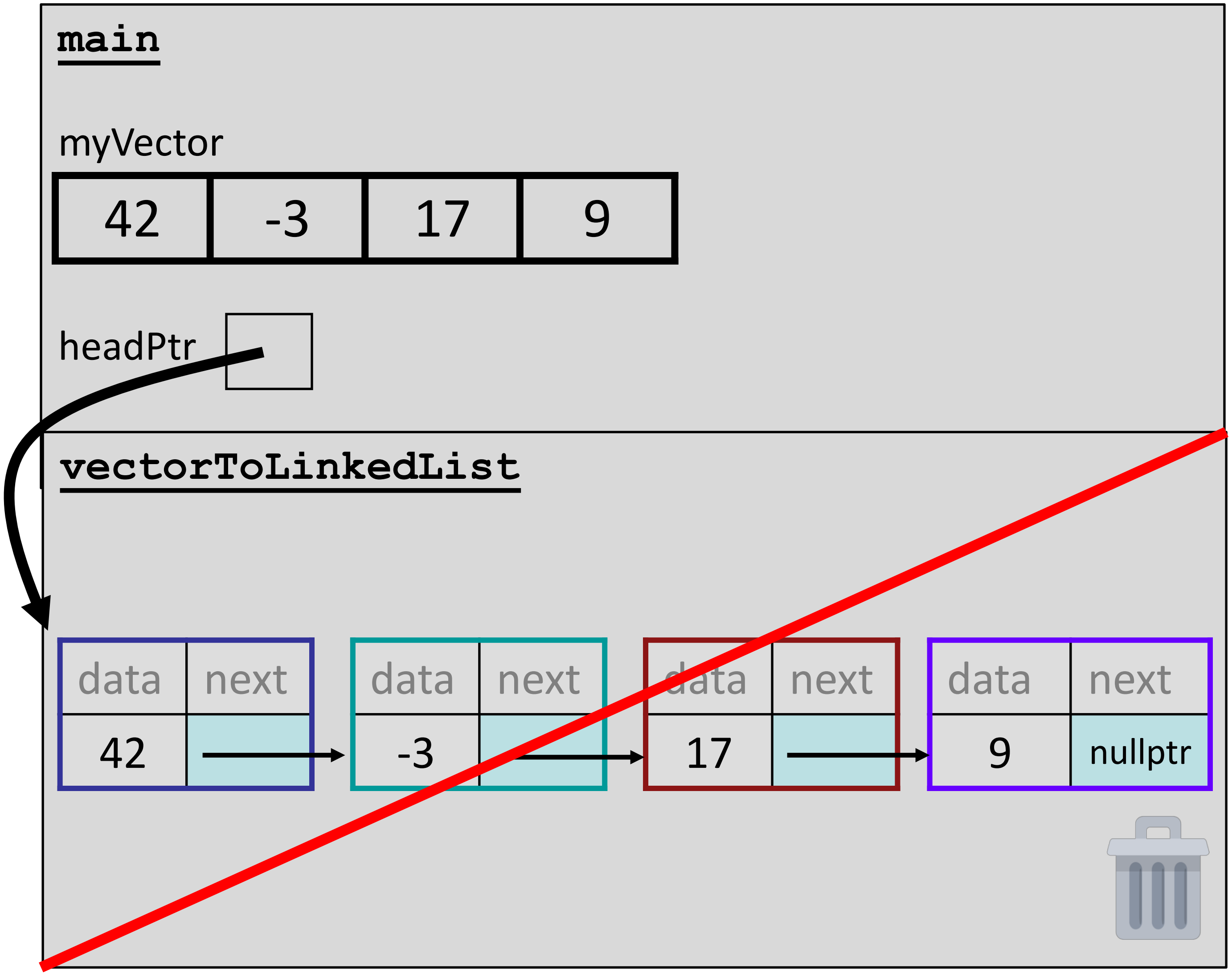
B. `temp = &list;` `list = temp.next;`

C. `temp.next = list->next;` `list->next = &temp;`

Creating a List

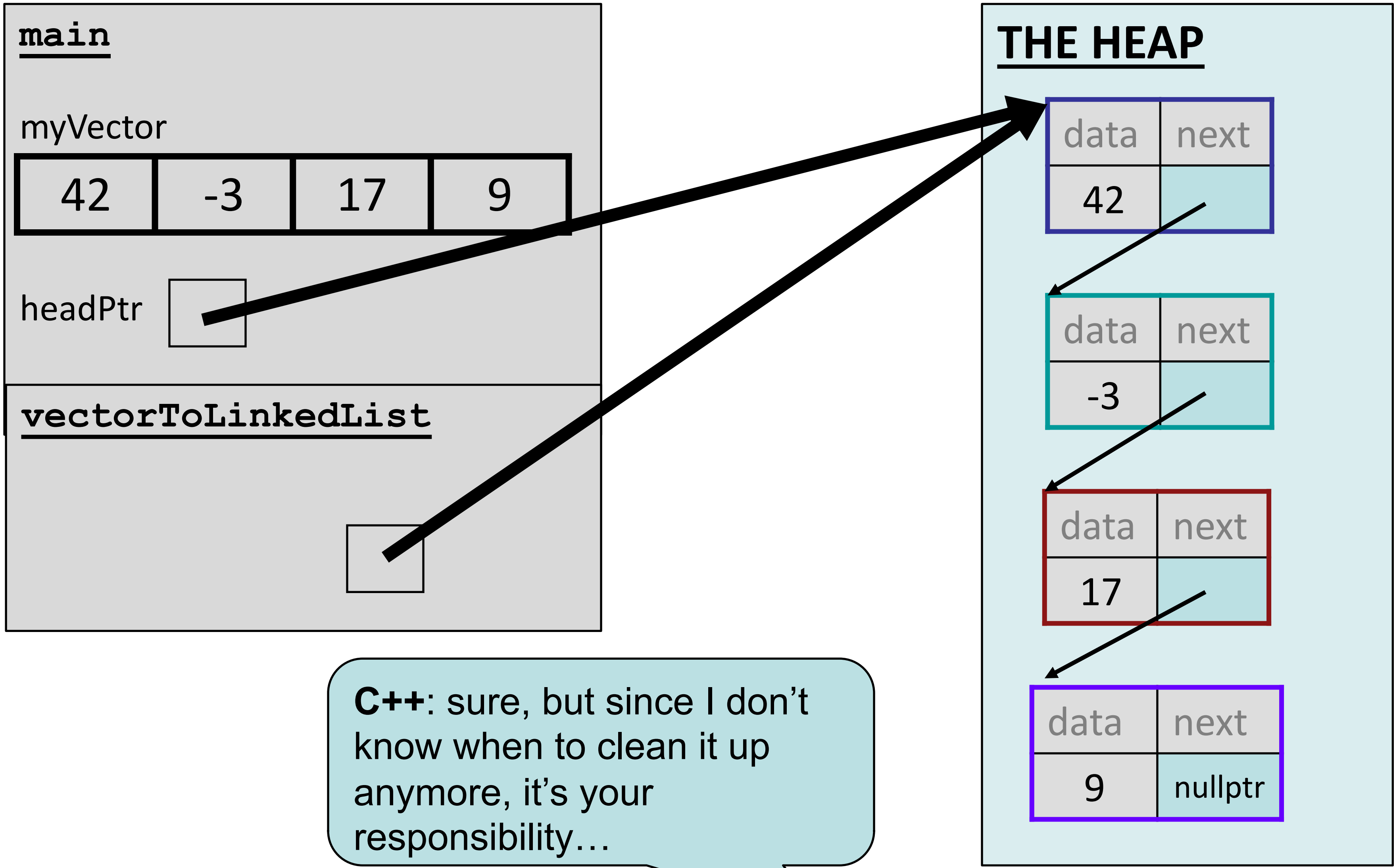
We need a way to have memory that doesn't get cleaned up when a function exits.

A New Kind of Memory



Us: hey C++, is there a way to make these variables in memory that isn't automatically cleaned up?

A New Kind of Memory



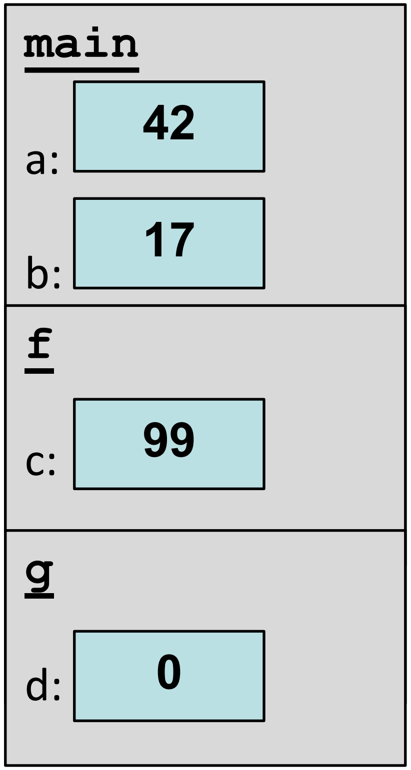
C++: sure, but since I don't know when to clean it up anymore, it's your responsibility…

The Stack

```
int main() {
    int a = 42;
    int b = 17;
    f();
}

void f() {
    int c = 99;
    g();
}

void g() {
    int d = 0;
}
```



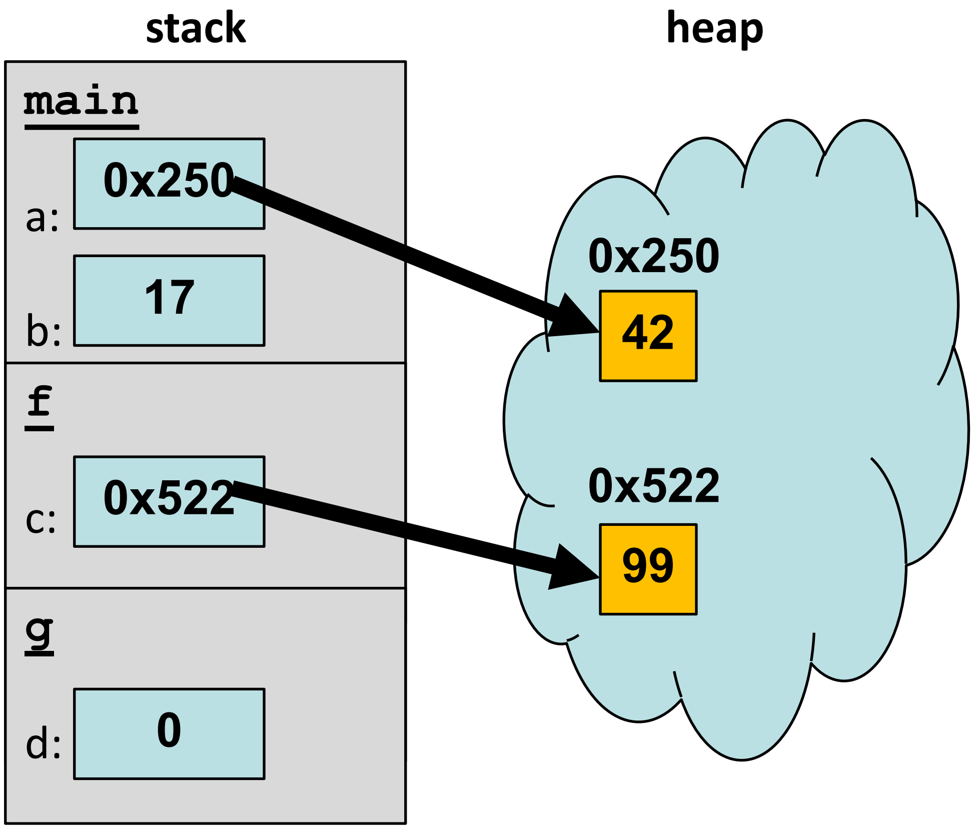
The **stack** is the place where all local variables live. Anything you declare as a local variable in a function lives on the stack. A function's stack "frame" goes away when the function returns.

The Heap

```
int new() {
    int* a = new int(42);
    int b = 17;
    f();
}

void f() {
    int* c = new int(99);
    g();
}

void g() {
    int d = 0;
}
```

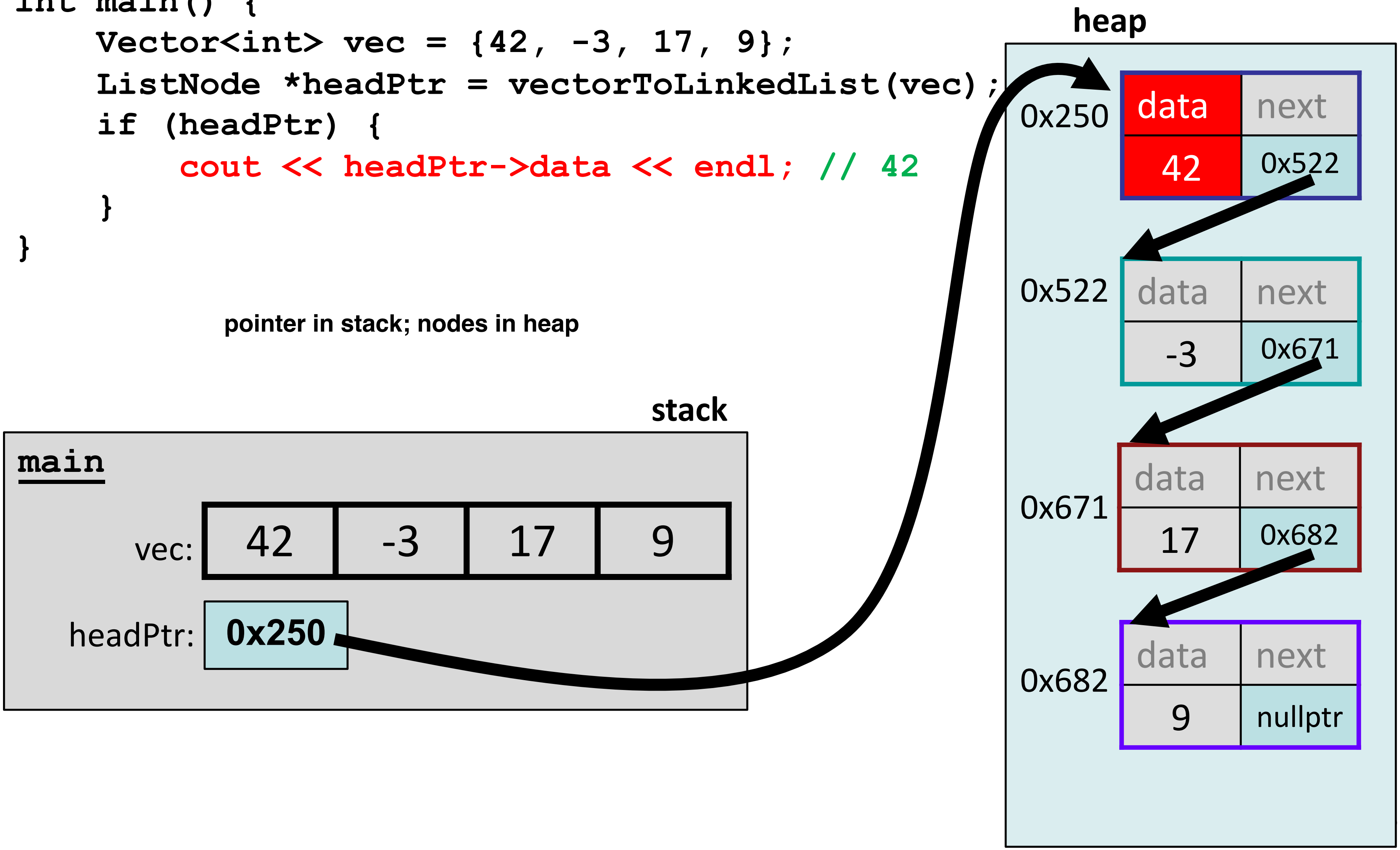


The **heap** is a part of memory that you can manage yourself. Unlike the stack, the memory only goes away when you delete it yourself. To allocate memory on the heap, use the **new** keyword. **new** returns a *the address on the heap of the new memory*.

Creating a List

```
int main() {
    Vector<int> vec = {42, -3, 17, 9};
    ListNode *headPtr = vectorToLinkedList(vec);
    if (headPtr) {
        cout << headPtr->data << endl; // 42
    }
}
```

pointer in stack; nodes in heap



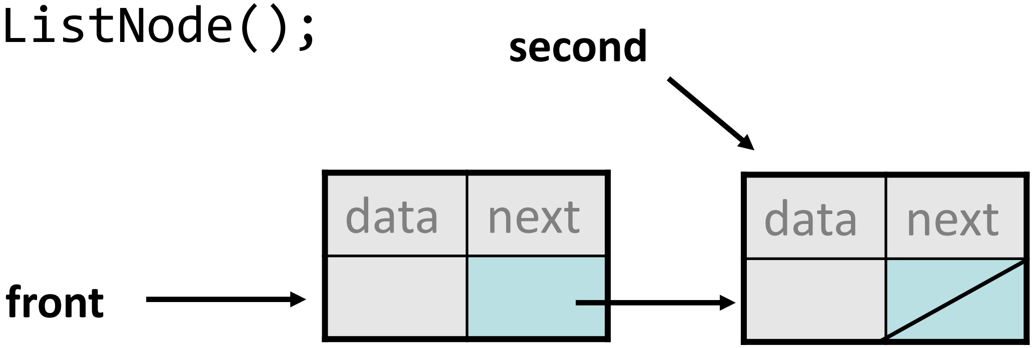
防内存泄漏，要用delete删除，相当于c中的free

Cleaning Up

- If we allocated memory on the heap and no longer need it, it is our responsibility to **delete** it.
- To do this, use the **delete** command and specify the *address on the heap for the memory you no longer need.*
- If you do not do this, your program is said to have a *memory leak*.

```
delete pointer;
```

```
ListNode* front = new ListNode();
ListNode* second = new ListNode();
front->next = second;
...
delete second;
delete front;
```



Implementing remove

```
void remove(ListNode*& front, int index) {
    if (index == 0) {
        ListNode* nodeToDelete = front;
        front = front->next;
        delete nodeToDelete;
    } else {
        ListNode* current = front;
        for (int i = 0; i < index - 1; i++) {
            current = current->next;
        }

        ListNode* nodeToDelete = current->next;
        current->next = current->next->next;
        delete nodeToDelete;
    }
}
```

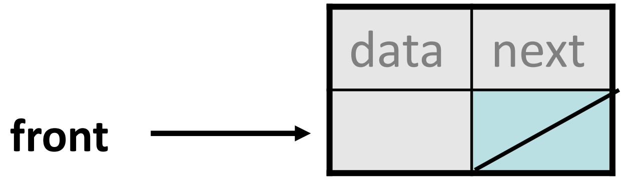
Cleaning Up

- If you delete something on the heap, it just deletes the *heap memory*, **not the pointer itself**. The pointer lives on the stack! You can reuse it to point to something else.
- Once you delete something on the heap, you should not refer to it again. Set a pointer to point somewhere else (or to **`nullptr`**) after you have deleted what it pointed to.

delete删除的不是ptr本身，而是其指向的位置；删完一个ptr指向位置之后最好将ptr设成nullptr或是别的具体的位置；没设置不要再次**调用/删除**！

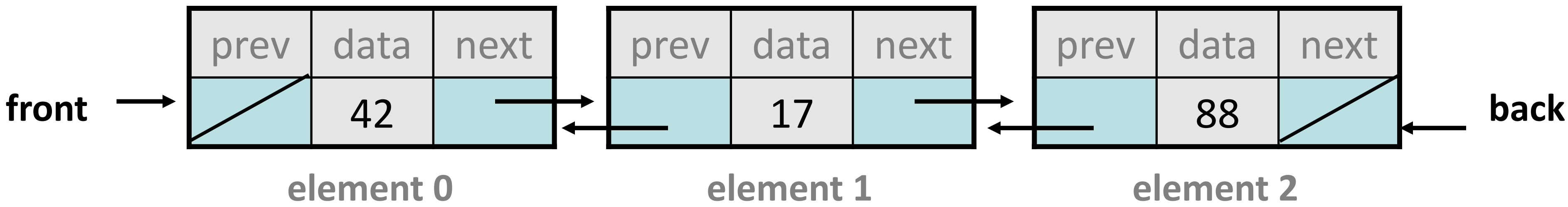
```
delete pointer;
```

```
ListNode* front = new ListNode();
...
delete front;
front = otherPtr->next;
```



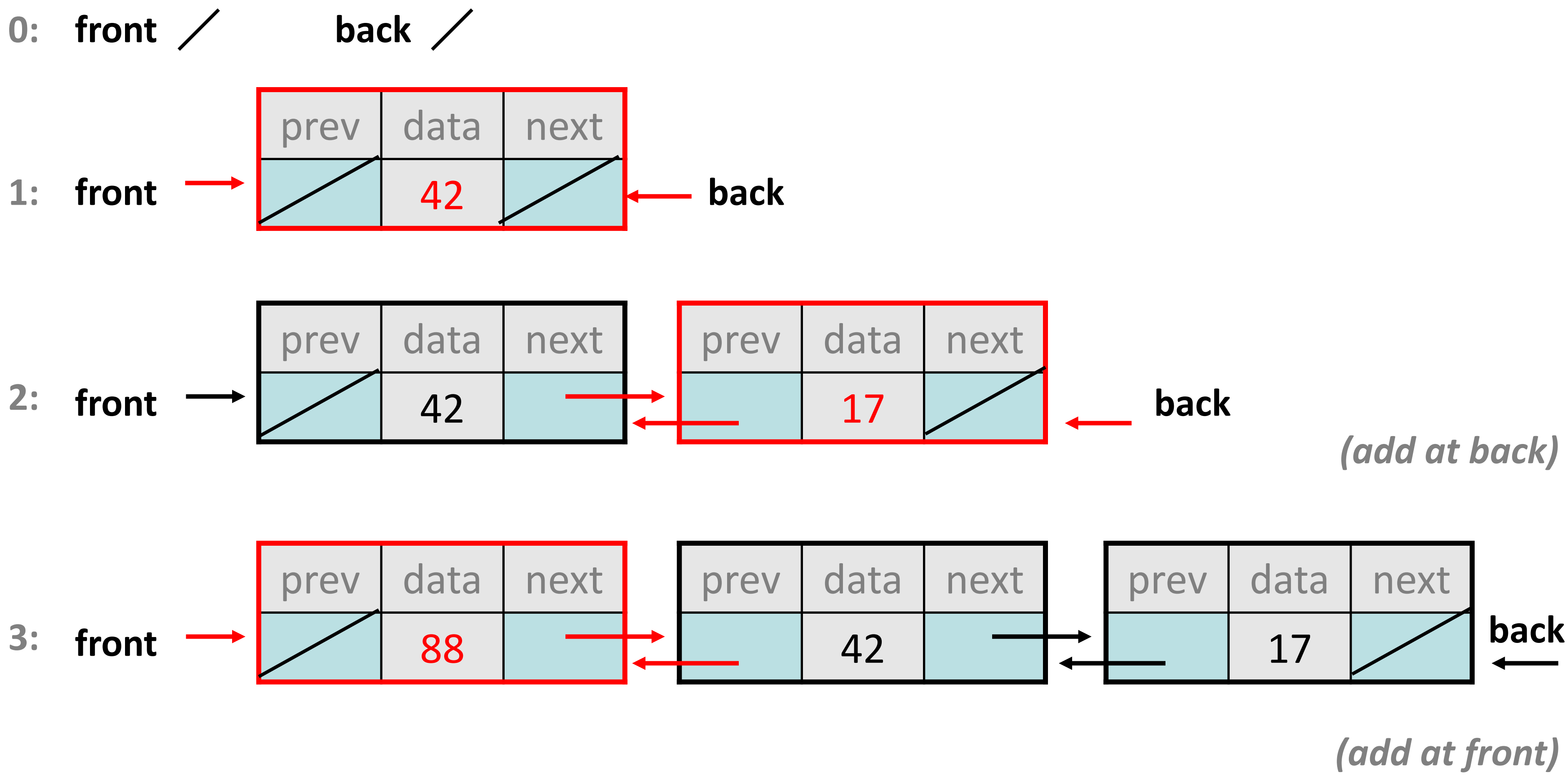
Doubly linked list

- **doubly linked list**: Each node has a pointer to next and prev node.
  - Allows walking forward and backward in list efficiently.
  - Overall list often maintains a **back** pointer to end of list.



D.L. list growth

- State of a doubly linked list of 0, 1, 2, *N* nodes:



D.L. list remove

- When removing a node, must change two pointers.
  - Might also need to change front and/or back.
  - Example: Try removing each of the three nodes below.