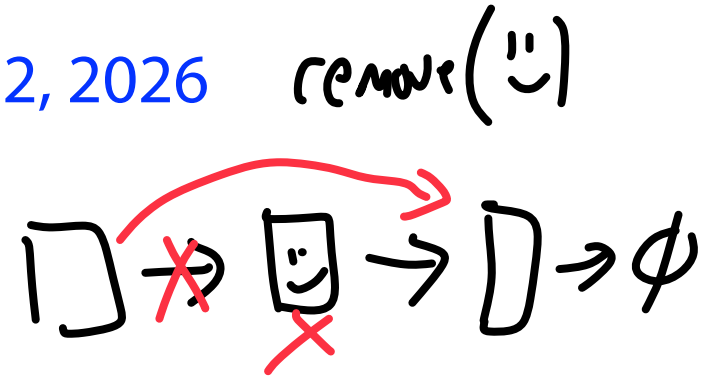
Data Structures

Linked Lists & (maybe) Array Lists

CS 225

Brad Solomon

September 2, 2026



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Monday, August 24th 6 PM | *CIF Room 4025*
Monday, August 31st 7 PM | *Wohlers Room 141*

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Case Training + Meet & Greet

Wednesday, September 2nd, 6 PM | *CIF Room 4025*

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Women in Consulting Night

Friday, September 4th 5 PM | *Wymer 1010*

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Application Deadlines

Cycle 1 - Friday, August 28th @ 11:59 PM
Cycle 2 - Friday, September 4th @ 11:59 PM

Learning Objectives

Review the importance of index in a linked list

Finish implementing the List ADT (as a linked list)

Discuss data variables for implementing array lists

Explore the List ADT (as an array list)

List ADT

A list is an **ordered** collection of items

Items can be either **heterogeneous** or **homogenous**

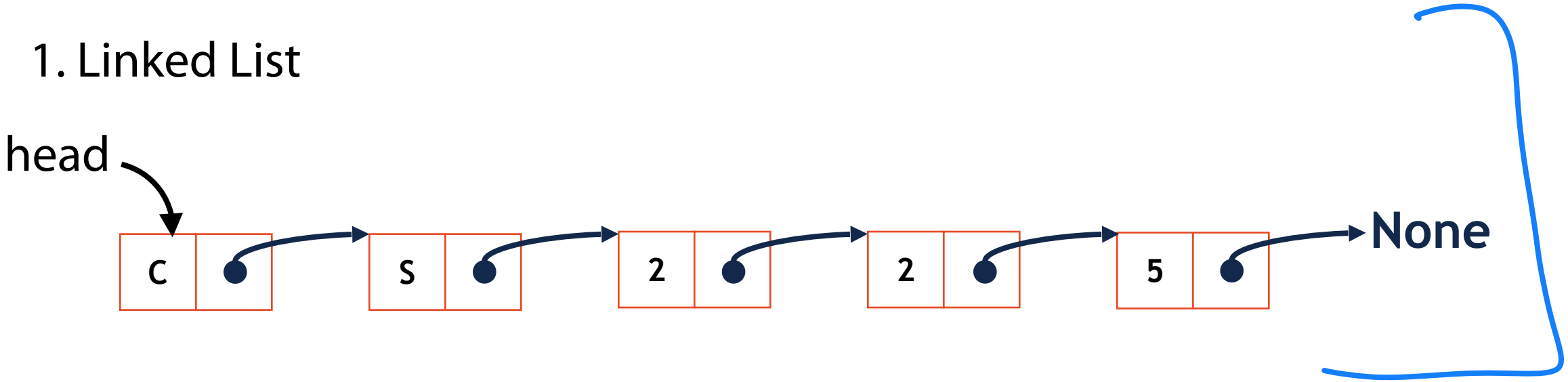
The list can be of a **fixed size** or is **resizable**

A minimal set of operations (that can be used to create all others):

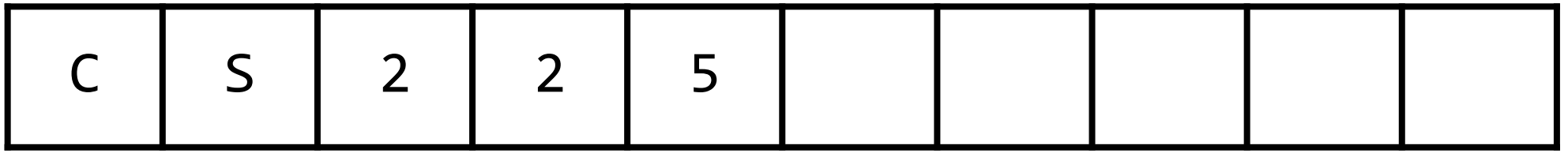
1. Insert
2. Delete
3. isEmpty
4. getData
5. Create an empty list

List Implementations

1. Linked List

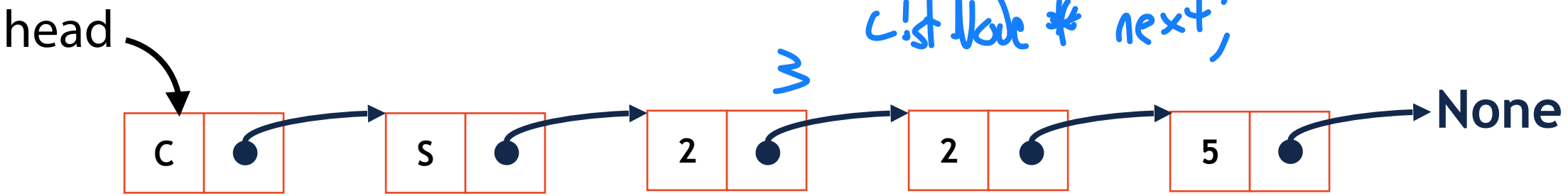


2. Array List



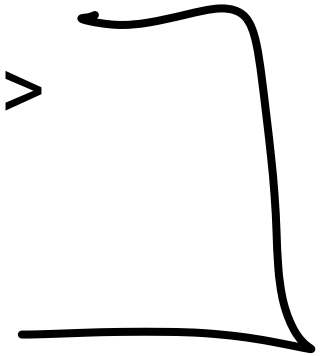
Where we left off…

ListNode {
↳ t & data
ListNode * next;



1. Singly linked list only accesses forward —>

↳ B/c we only have next



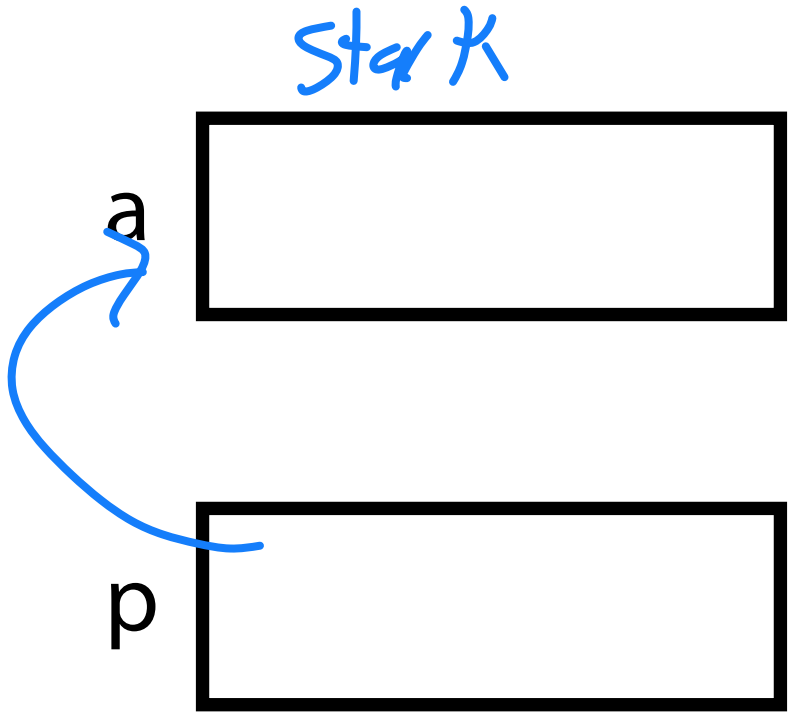
2. To insert in arbitrary position we need to access what value?

↳ prev → next is the reference (to a pointer) that we modify

A review on memory management

A pointer stores a memory address

```
int a = 3;

int *p = &a;
```



A review on memory management

A reference assigns a new name to a variable

```
int a = 3;

void blackBox(int & y){
     y = 4;
}

blackBox(a);
```

y = a

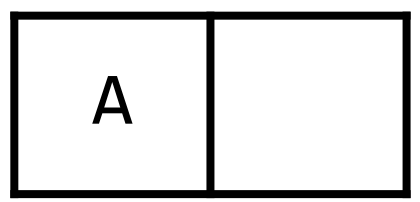
y inside this scope

a (local stack)

A review on memory management

Now lets think in terms of linkedLists…

```
ListNode* a = new ListNode(A);
```




```
void blackBox(ListNode* & y){
    y = new ListNode(B);
}
```

```
blackBox(a->next);
```

ref to

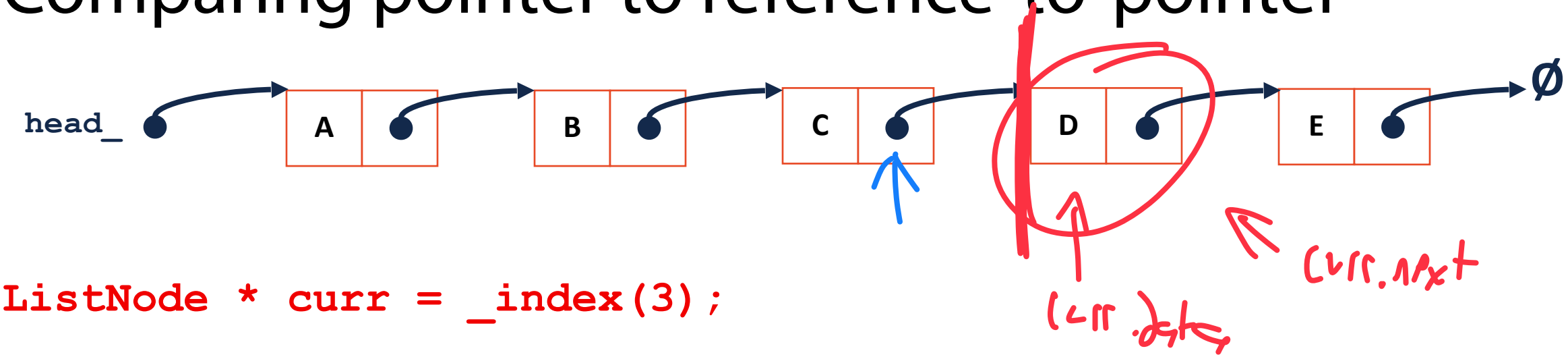
List Node *

(*a).next

List.hpp

```
1  // Iterative Solution:
2  template <typename T>
3  typename List<T>::ListNode *& List<T>::_index(unsigned index) {
4    if (index == 0) { return head; }
5    else {
6      ListNode *curr = head;
7      for (unsigned i = 0; i < index - 1; i++) {
8         curr = curr->next;
9      }
10     return curr->next;
11   }
12 }
```

Comparing pointer to reference-to-pointer




```
ListNode * curr = _index(3);
```

We can access **curr->data** and **curr->next** but not **previous.next**

```
ListNode *& curr = _index(3);
```

We can access **curr.data**, **curr.next** and...

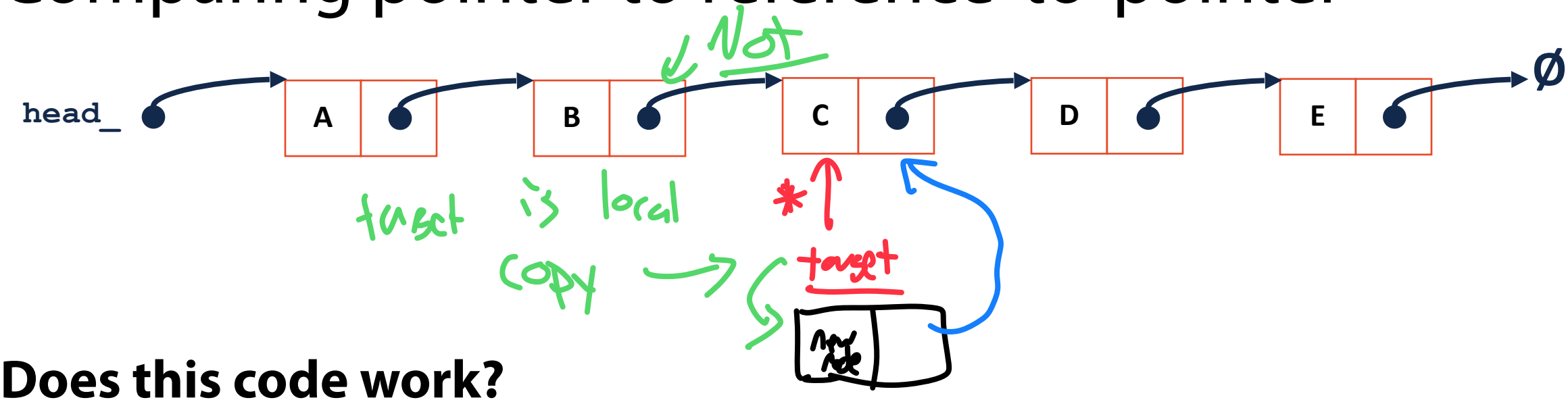
curr == previous.next

can modify prev -> next

ref

Included is the Bonus Video version of the next few slides

Comparing pointer to reference-to-pointer

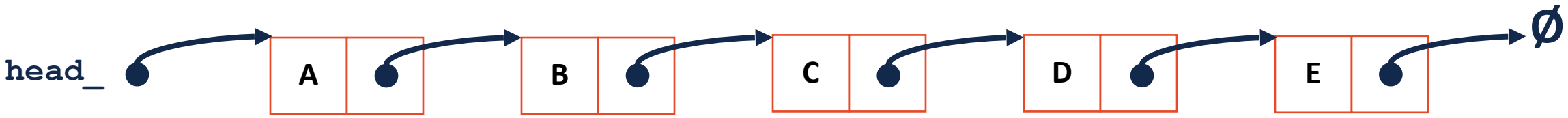


Does this code work?

```
void insertAtNode(ListNode* target, int value) {
    ListNode* newNode = new ListNode(value);
    newNode->next = target;
    target = newNode;
}
```

Join Code: 225

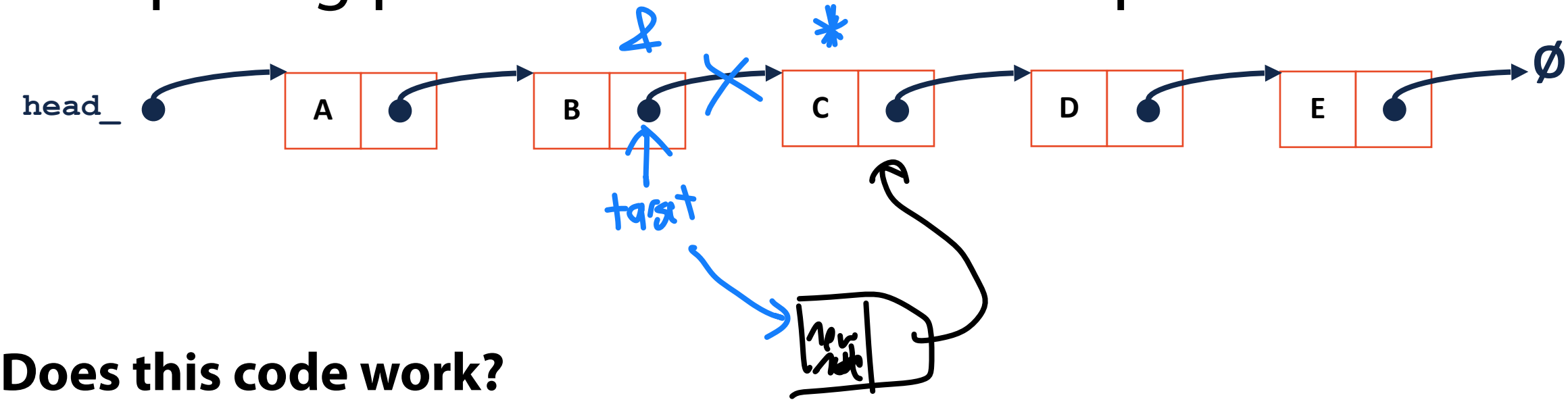
Comparing pointer to reference-to-pointer



This does not work! The pointer is a local stack object!

```
void insertAtNode(ListNode* target, int value) {
    ListNode* newNode = new ListNode(value);
    newNode->next = target;
    target = newNode; // Only updates local copy!
}
```

Comparing pointer to reference-to-pointer

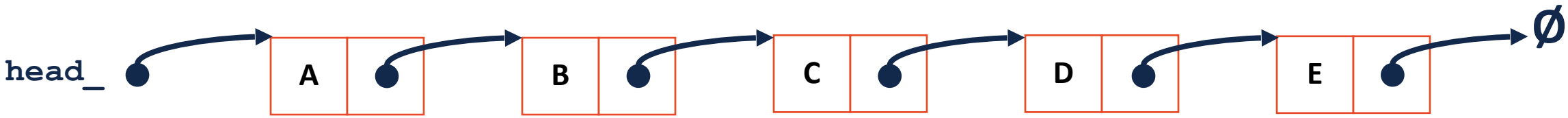


Does this code work?

```
void insertAtNode(ListNode*& target, int value) {

    ListNode* newNode = new ListNode(value);

    newNode->next = target;

    target = newNode;
}
```

Join Code: 225

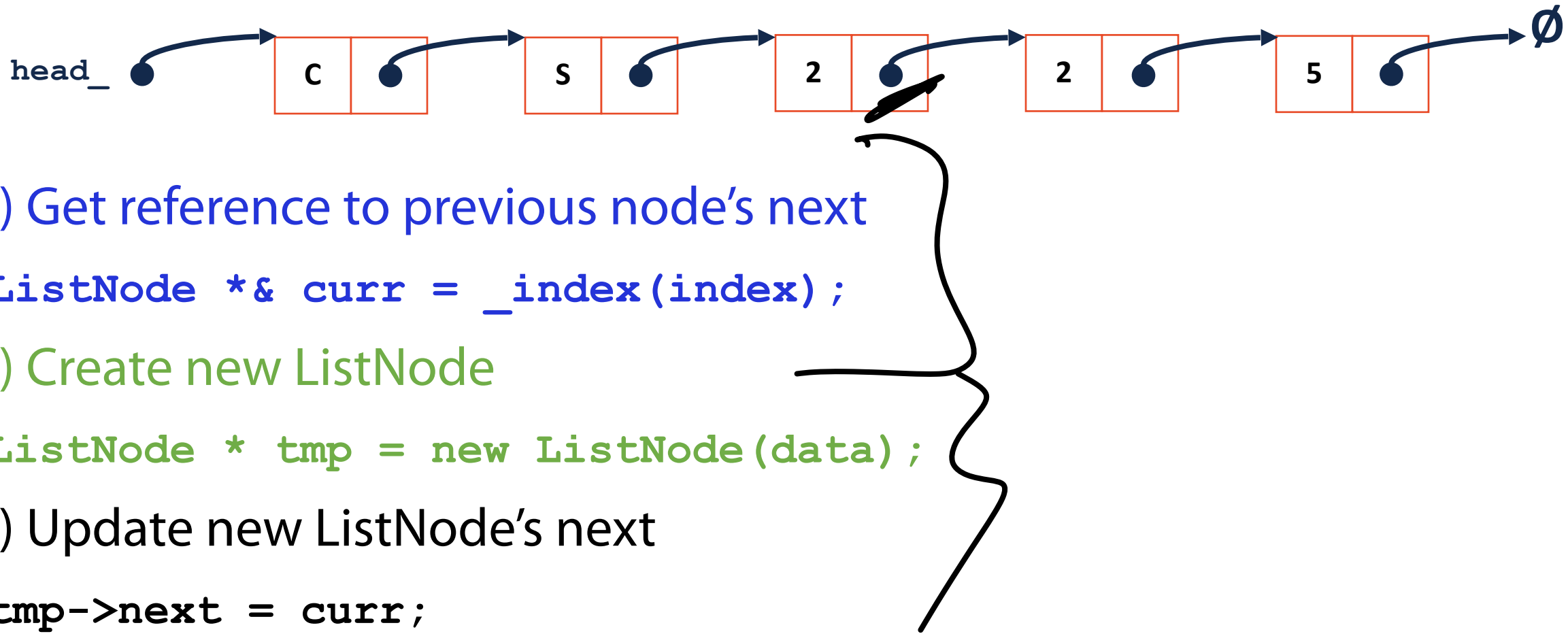
Comparing pointer to reference-to-pointer



Yes — because the reference is to a specific memory allocation

```
void insertAtNode(ListNode*& target, int value) {

    ListNode* newNode = new ListNode(value);

    newNode->next = target;

    target = newNode;
}
```

Linked List: `insert(data, index)`



1) Get reference to previous node's next

```
ListNode *& curr = _index(index);
```

2) Create new ListNode

```
ListNode * tmp = new ListNode(data);
```

3) Update new ListNode's next

```
tmp->next = curr;
```

4) Modify the previous node to point to new ListNode

```
curr = tmp;
```

Lets compare...

List.hpp

```
1
2  template <typename T>
3  void List<T>::insertAtFront(const T& t)
4  {
5    ListNode *tmp = new ListNode(t);
6
7    tmp->next = head_;
8
9    head_ = tmp;
10
11 }
12
13
14
15
16
17
18
19
20
21
22
```

all O(1) ops

```
1
2  template <typename T>
3  void List<T>::insert(const T & data,
4  unsigned index) {
5
6
7
8    ListNode *& curr = _index(index);
9
10
11
12   ListNode * tmp = new ListNode(data);
13
14
15
16   tmp->next = curr;
17
18
19
20   curr = tmp;
21 }
22
```

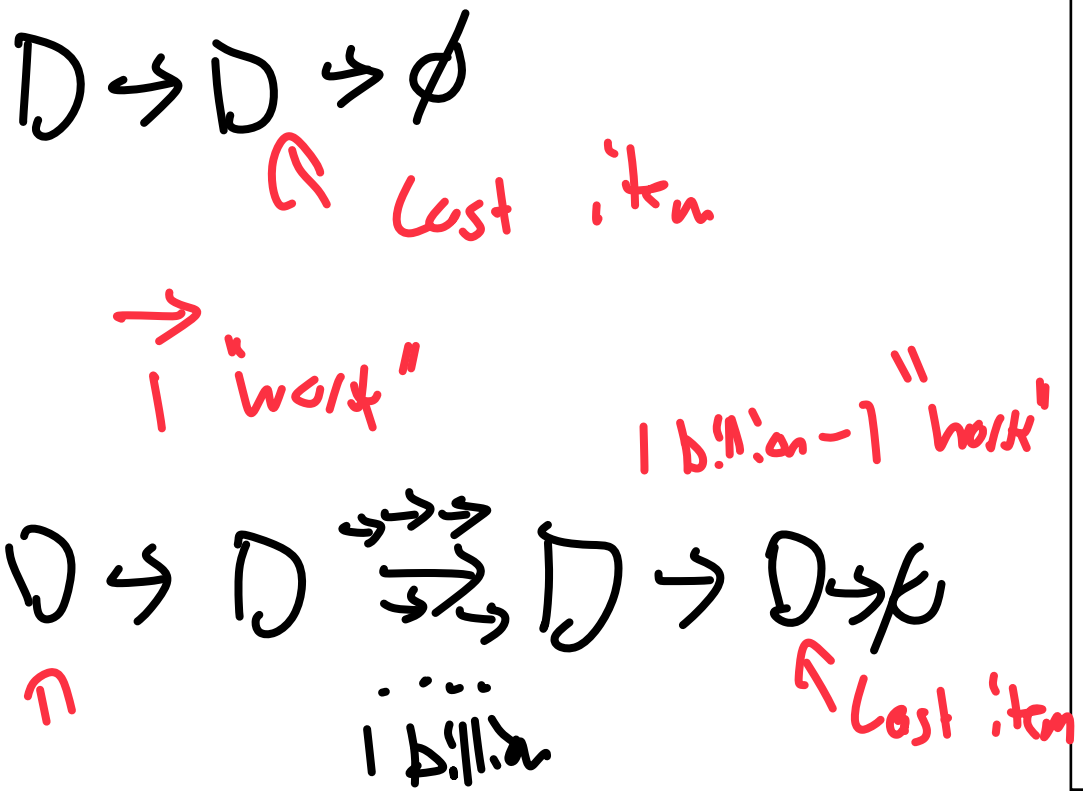
finding point, is slow

modifying at location in LL is fast

What is the Big O of insert (given list of size n)?

15% O(log n)

85% O(n)



List.hpp

```
1
2  template <typename T>
3  void List<T>::insert(const T & data,
4  unsigned index) {
5
6
7
8    ListNode *& curr = _index(index);
9
10
11
12   ListNode * tmp = new ListNode(data);
13
14
15
16   tmp->next = curr;
17
18
19
20   curr = tmp;
21 }
22
```

↳ ??? O(n)

↳ O(1)

↳ O(1)

↳ O(1)

Join Code: 225

List Random Access [ ]

Given a list L, what operations can we do on L[ ]?

↳ GetData()

↳ SetData()

x = L[i];

L[i] = x;

Only type T &

What return type should this function have?

L[x] is type ListNode *

L[x]->data

List Random Access [ ]

What return type should this function have?

Join Code: 225

```
[template <class T>]
```

(A) `T &`

36%

(B) `ListNode`

8%

(C) `ListNode *`

13%

This could work

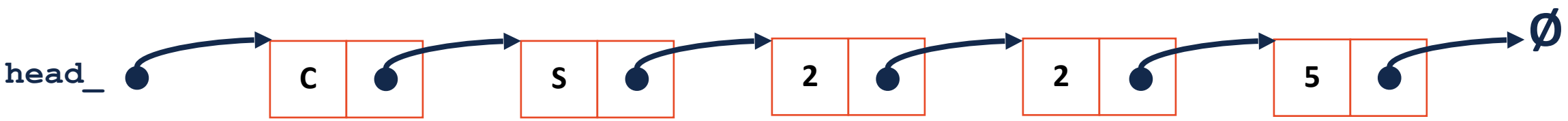
(D) `ListNode *&`

40%

Not the expected interface

List.hpp

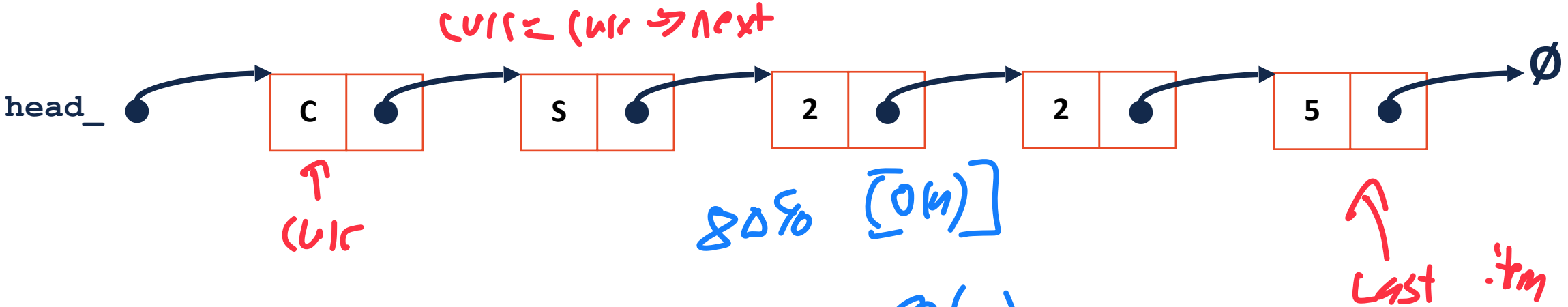
```
48 template <typename T>
49 T & List<T>::operator[](unsigned index) {
50
51         ListNode * tmp = _index(index);
52
53
54
55         return tmp->data;
56
57
58 }
```



List.hpp

```
48 template <typename T>
49 T & List<T>::operator[](unsigned index) {
50
51
52 ListNode *&new_node = _index(index);
53
54
55 return new_node->data;
56
57
58 }
```

Join Code: 225



What is the Big O of random access?

Linked List: remove(<parameters>)

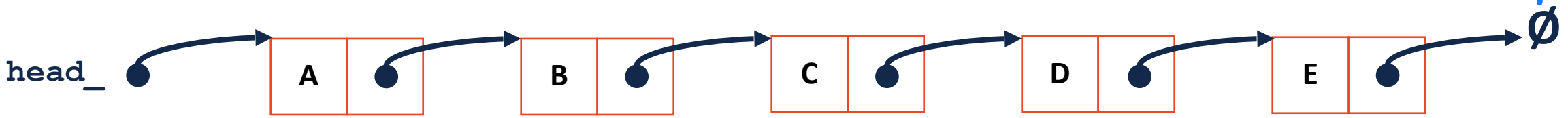
What input parameters make sense for remove?

remove (unsigned index)

remove (T & value)

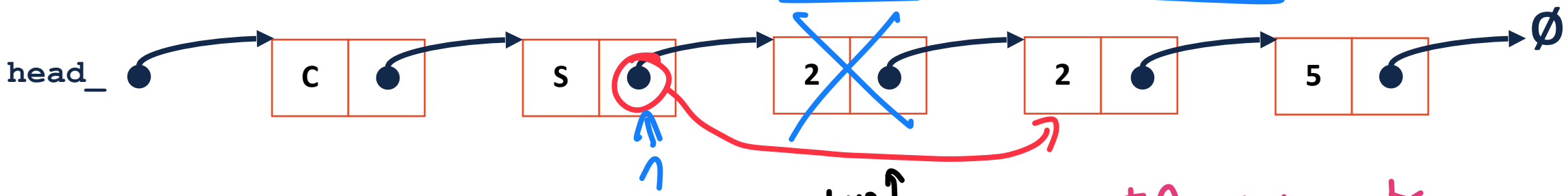
remove (ListNode *& myN)

remove (ListNode *)
can work but will be slower & more complex



Linked List: remove(ListNode *& n)

(target)




```
ListNode * tmp = n;
```

O(1)

```
n = n->next;
delete tmp;
```

If access to specific mem address, linked list remove is fast!

remove(ListNode *& n)

1) Loop through list until curr->next == n

O(n)

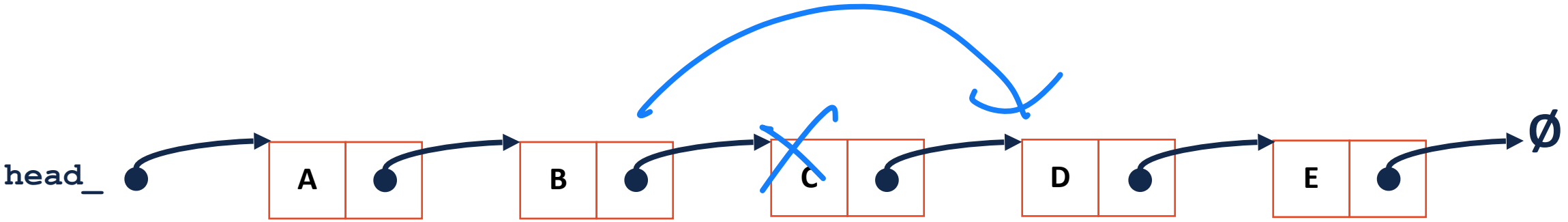
List.hpp

```
103  template <typename T>
104  T List<T>::remove(ListNode *& node) {
105
106  ListNode * temp = node;
107  node = node->next;
108  T data = temp->data;
109  delete temp;
110  return data;
111
112  }
```

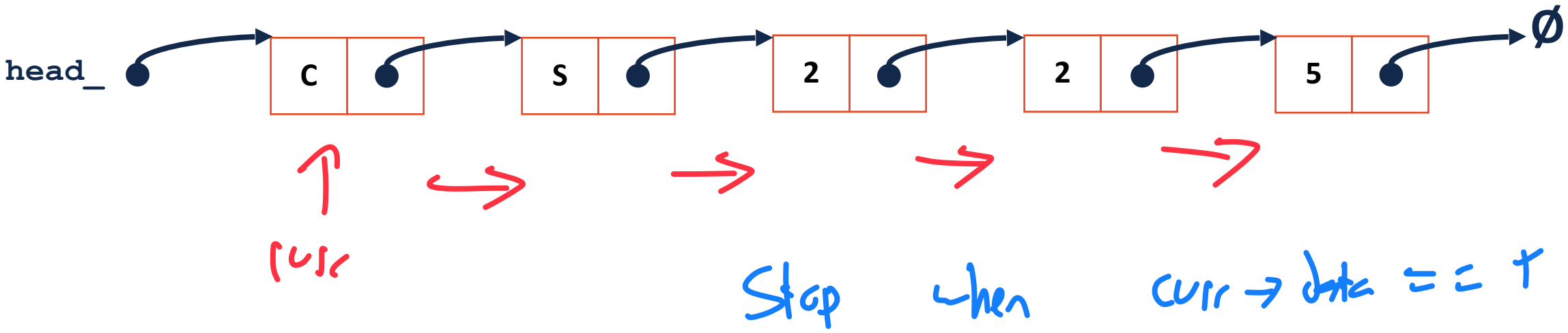
local copy goes out of scope

If I want to return T I either return by value or I add it to heap in remove

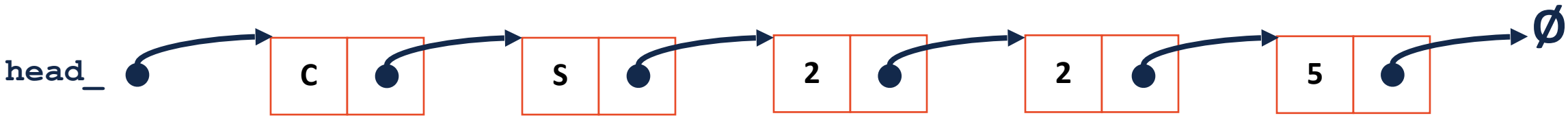
poor choice



Linked List: `remove(T & data)`



Linked List: `remove`



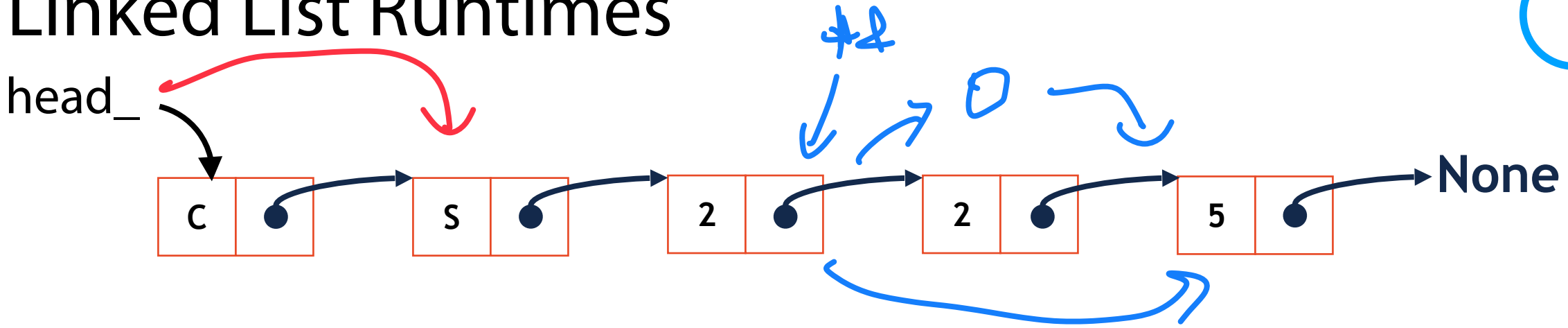
Running time for **`remove(ListNode *&)`**

↳ O(1)

Running time for **`remove(T & data)`**

↳ O(n)

Linked List Runtimes



	@Front	@RefPointer	@Index
Insert	O(1)	O(1)	O(n)
Delete	O(1)	O(1)	O(n)

Thinking critically about linked lists…

What is the runtime to filter a list of all odd valued items?

(A) O(1)

(B) O(log n)

(C) O(n)

(D) O(n^2)

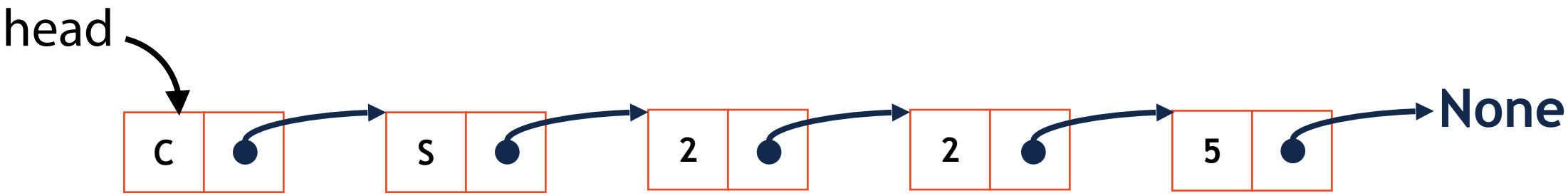
Thinking critically about linked lists…

An O(n) runtime seems bad (and is) for finding a single item.

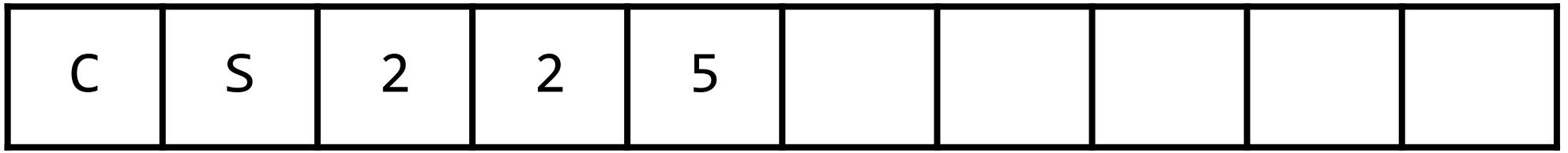
When might you want to use a linked list?

List Implementations

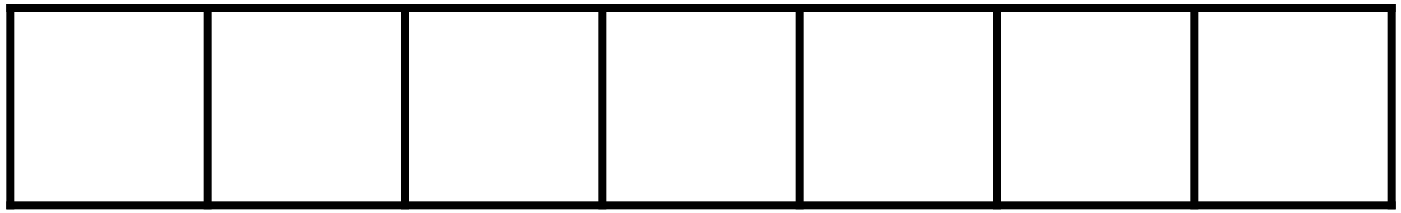
1. Linked List



2. Array List



Array List



An array is allocated as continuous memory.

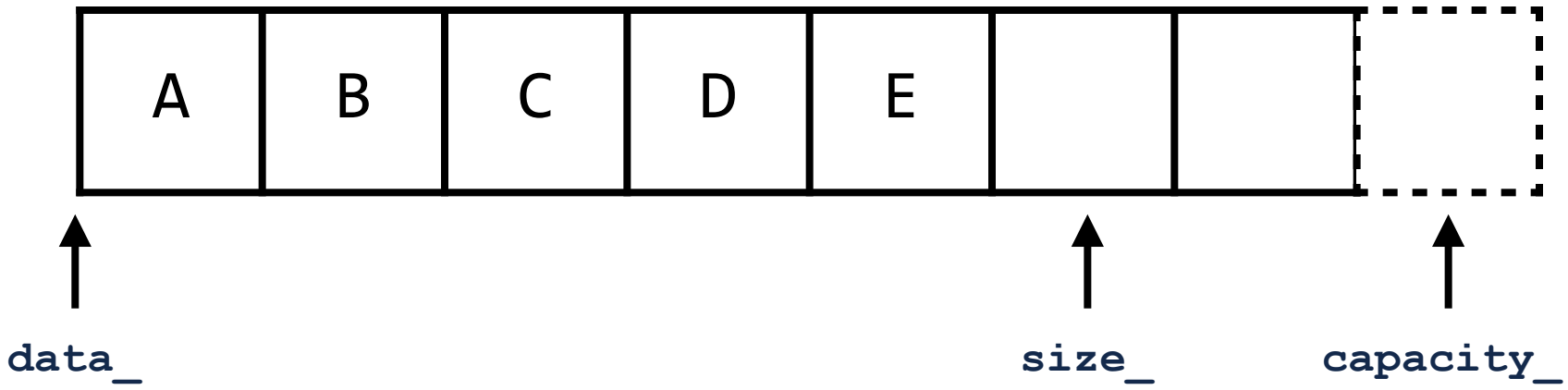
Three values are necessary for efficient array usage:

1)

2)

3)

Array List



In C++, vector is implemented as:

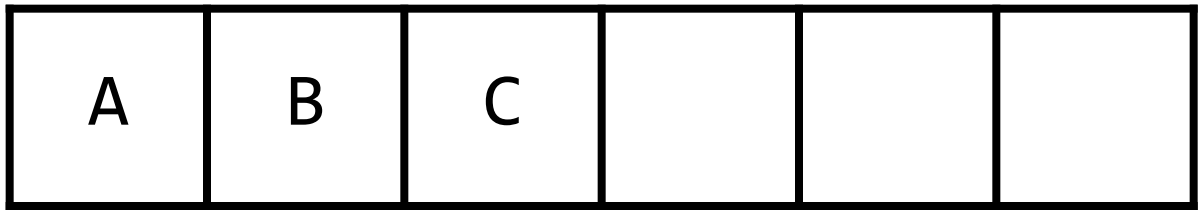
1) **Data:** Stored as a pointer to array start

2) **Size:** Stored as a pointer to the next available space

3) **Capacity:** Stored as a pointer past the end of the array

List.h

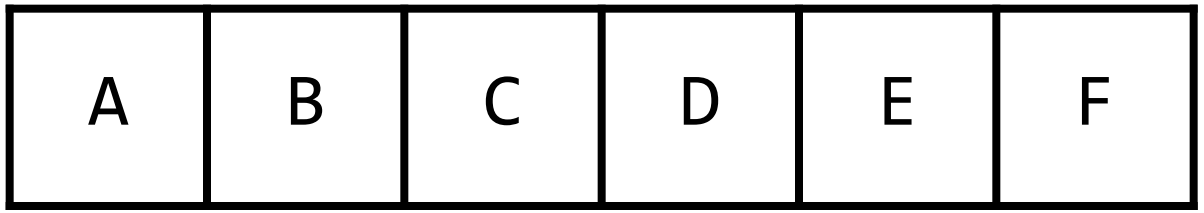
```
 1  #pragma once
 2
 3  template <typename T>
 4  class List {
 5  public:
…       /* --- */
25  private:
26    T *data_;
27
28    T *size_;
29
30    T *capacity_;
…
        /* --- */
    };
```



If I want to know the number of items in the array:

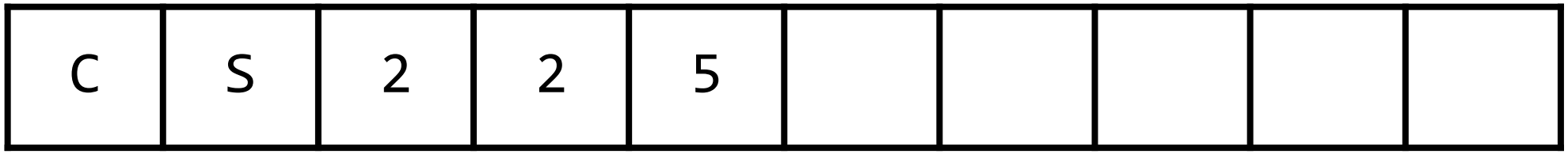
List.h

```
 1  #pragma once
 2
 3  template <typename T>
 4  class List {
 5  public:
 …      /* --- */
25  private:
26    T *data_;
27
28    T *size_;
29
30    T *capacity_;
 …
        /* --- */
    };
```

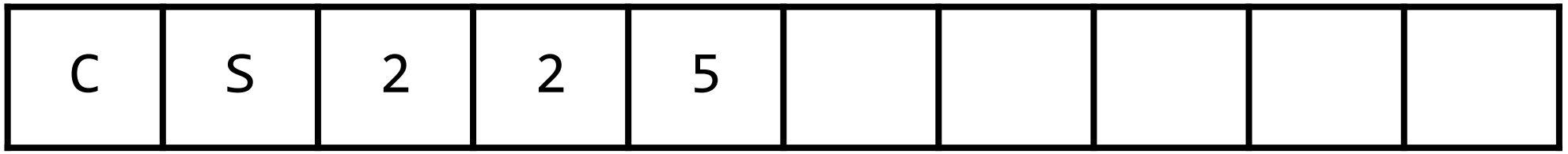


How do I know if I'm at capacity?

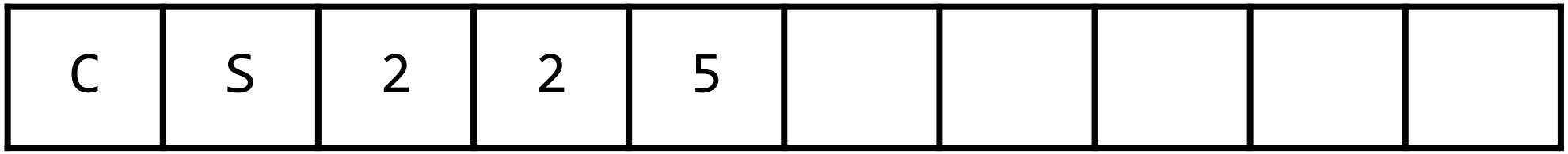
Array List: [ ]



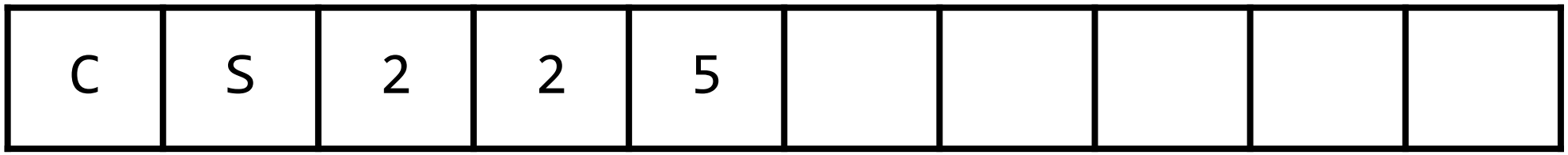
Array List: `insertFront(data)`



Array List: `insertBack(data)`



Array List: `insert(data, index)`



Array List: addspace(data)