Data Structures

Linked Lists

CS 225

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Learning Objectives

Review fundamentals of linked lists

Implement insert, index, and remove operations

Discuss pointers vs references-to-pointers

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

List.h

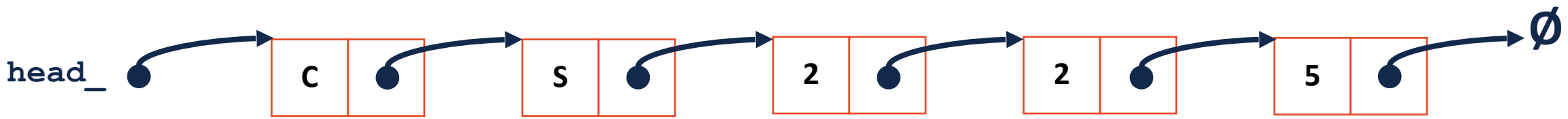
```
 1  template <class T>
 2  class List {
 3    public:
 4      /* ... */
 5    private:
…       class ListNode {
28        T & data;
29        ListNode * next;
30        ListNode(T & data) :
31         data(data), next(NULL) { }
32      };

33      ListNode *head_;
34  };
```

Join Code: 225

Can we access **x** from **y**?

Can we access **y** from **x**?



ListNode x ListNode y

List.h

```
 1  #pragma once
 2
 3
 4  class List {
 5    public:
…       /* ... */
28    void insertAtFront(const T& t);
29
30    private:
31      class ListNode {
32        T & data;
33        ListNode * next;
34        ListNode(T & data) :
35         data(data), next(NULL) { }
36      };
37
38      ListNode *head_;
39
40      /* ... */
…
…   };
…
79
```

What is missing in this code?

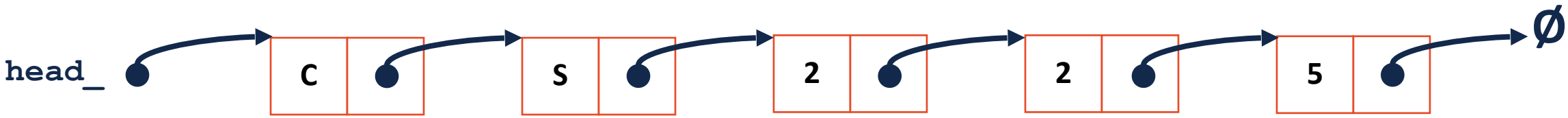
List.h

```
 1  #pragma once
 2
 3  template <typename T>
 4  class List {
 5    public:
 …      /* ... */
28    void insertAtFront(const T& t);
29
30    private:
31      class ListNode {
32        T & data;
33        ListNode * next;
34        ListNode(T & data) :
35         data(data), next(NULL) { }
36      };
37
38      ListNode *head_;
39
40      /* ... */
 …
 …  };
 …
79  #include "List.hpp"
```

List.hpp

```
 1
 2
 3
 4  void List<T>::insertAtFront(const T& t)
 5  {
 6
 7
 8
 9
10
11
12
13
14
15
16
17
18
19
20
21
22  }
```

Linked List: `insertAtFront(data)`



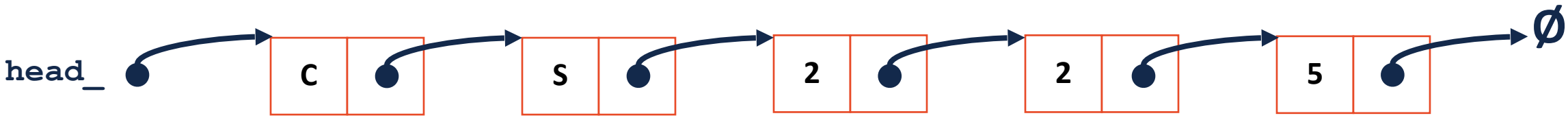
List.h

```
1  #pragma once
2
3  template <typename T>
4  class List {
5    public:
…      /* ... */
28   private:
29     class ListNode {
30       T & data;
31       ListNode * next;
32       ListNode(T & data) :
          data(data), next(NULL) { }
33     };
34
35     ListNode *head_;
36
37     /* ... */
38
39 };
…
…
79 #include "List.hpp"
```

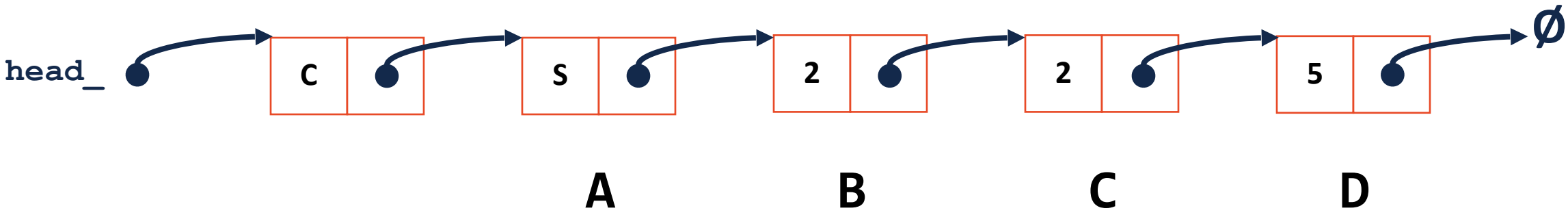
List.hpp

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

Linked List: `insert(data, index)`



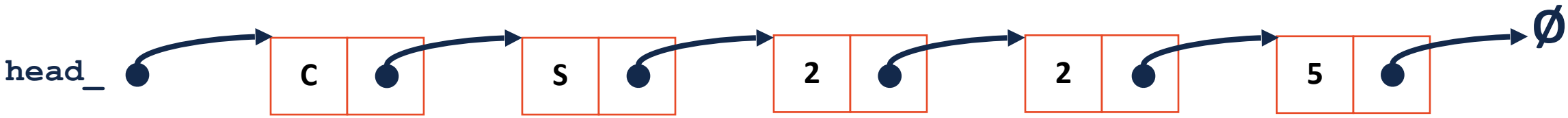
Linked List: `insert(data, index)` `insert(d,3)`



To insert a new ListNode at index 3, we need to **modify** which node?

Join Code: 225

Linked List: `insert(data, index)` `insert(d,3)`



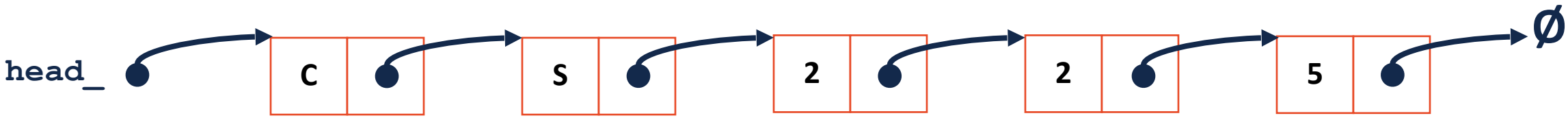
1) Get access to node @ position index - 1

We ***could*** code up a solution to insert which uses some previous var

But lets be smarter!

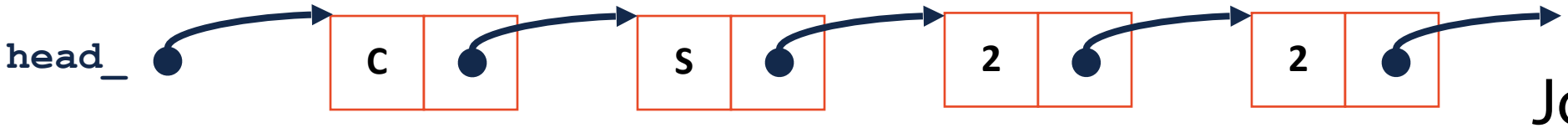
Coding tip from last lecture: **Consider the entire interface**

Linked List: `_index(index)`



Lets write one function which is useful for insert / remove AND find

Linked List: `_index(index)`



Join Code: 225

What should the return type of `_index()` be?

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

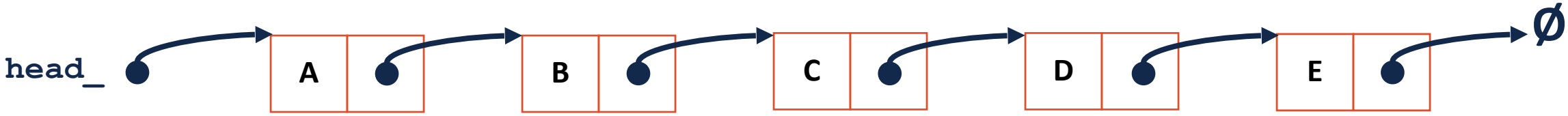
(A) `T &`

(B) `ListNode`

(C) `ListNode *`

(D) `ListNode *&`

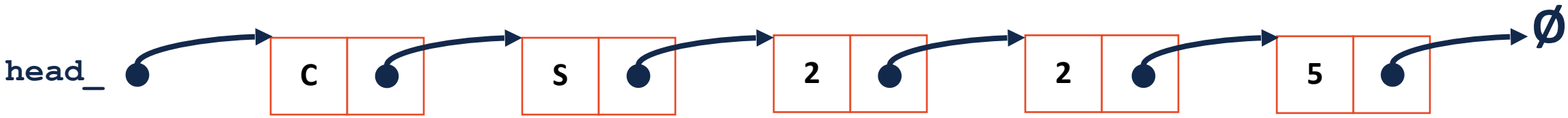
Comparing pointer to reference-to-pointer




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

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

LinkedList *& _index(index)



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 }
```

A brief tangent…

List.hpp

```
58  template <typename T>
59  typename List<T>::ListNode *& List<T>::_index(unsigned index){
60          return _index(index, head_)
61  }
```

```
63  template <typename T>
64  typename List<T>::ListNode *& List<T>::_index(unsigned index, ListNode *& root){
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80  }
```

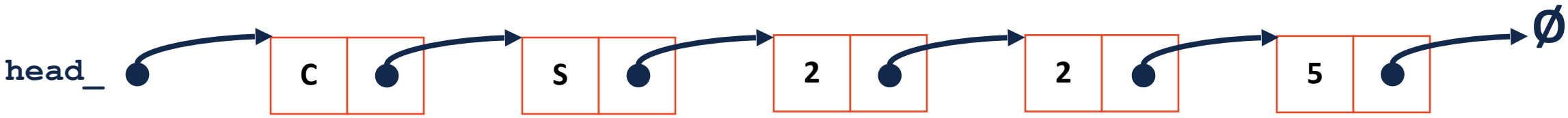
A brief tangent…

List.hpp

```
58  template <typename T>
59  typename List<T>::ListNode *& List<T>::_index(unsigned index){
60          return _index(index, head_)
61  }
```

```
63  template <typename T>
64  typename List<T>::ListNode *& List<T>::_index(unsigned index, ListNode *& root){
65
66
67
68      if (index == 0){ return root; }
69
70
71
72      if (root == nullptr){ return root; }
73
74
75
76      return _index(index - 1, root -> next);
77
78
79
80  }
```

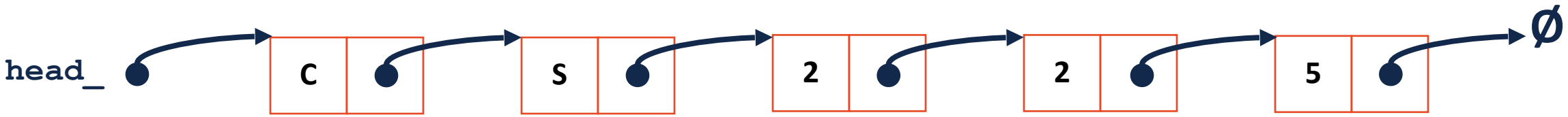
Linked List: `insert(data, index)`



1) Get reference to previous node's next

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

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…

```
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
```

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
```

List Random Access [ ]

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

What return type should this function have?

List Random Access [ ]

What return type should this function have?

Join Code: 225

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

(A) `T &`

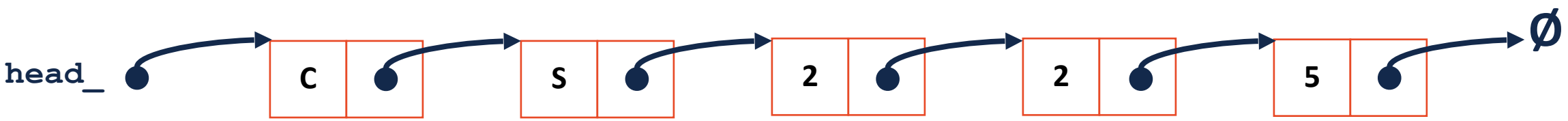
(B) `ListNode`

(C) `ListNode *`

(D) `ListNode *&`

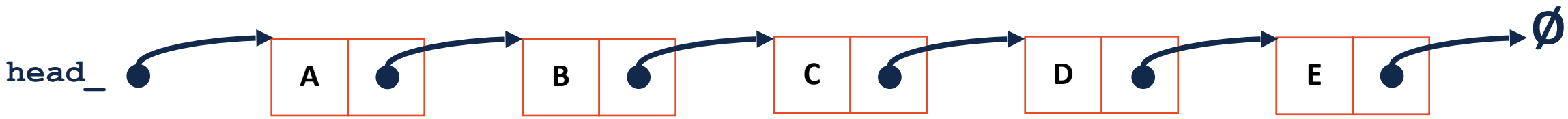
List.hpp

```
48 template <typename T>
49 T & List<T>::operator[](unsigned index) {
50
51
52
53
54
55
56
57
58 }
```

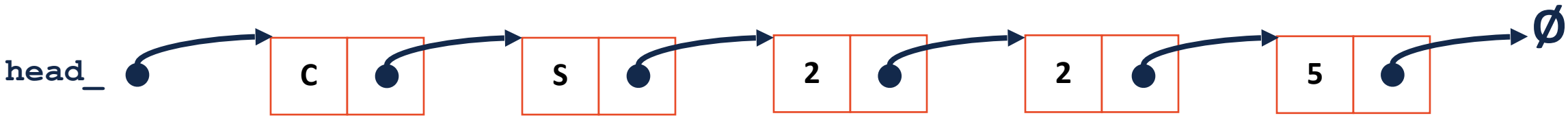


Linked List: `remove(<parameters>)`

What input parameters make sense for remove?

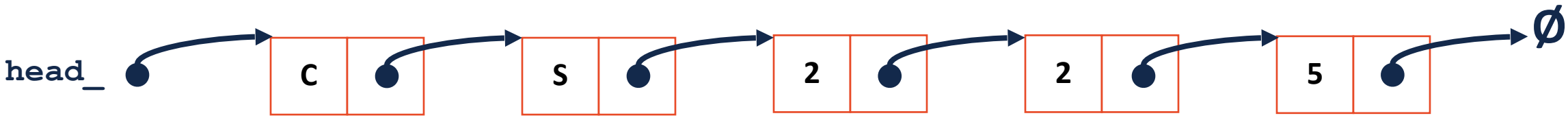


Linked List: `remove(ListNode *& n)`

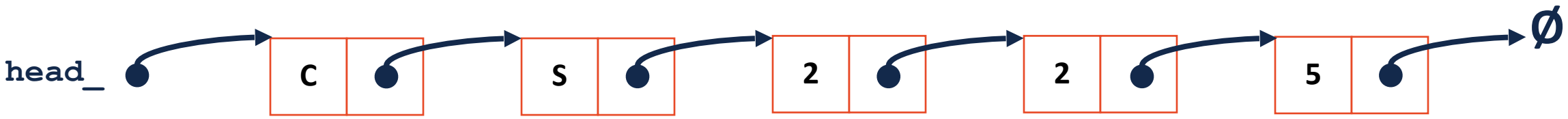


```
103 template <typename T>
104 T List<T>::remove(ListNode *& node) {
105
106
107
108
109
110
111
112 }
```

Linked List: `remove(T & data)`



Linked List: `remove`

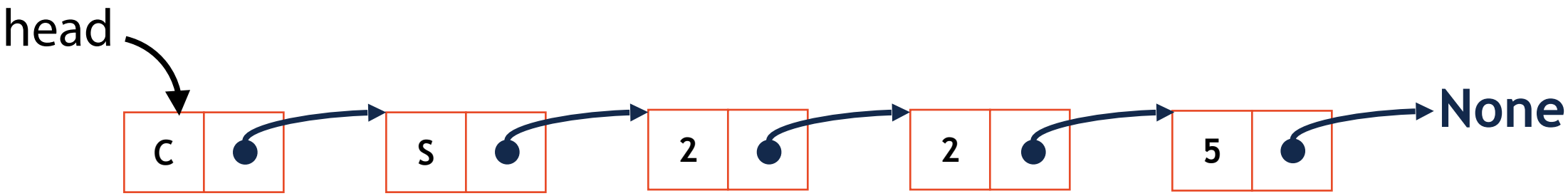


Running time for **`remove(ListNode *&)`**

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

List Implementations

1. Linked List



2. Array List