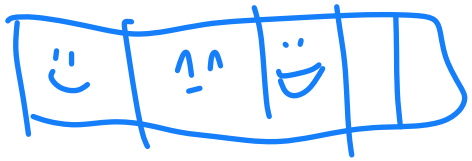
Data Structures

Linked Lists & Array Lists

CS 225

Brad Solomon

September 5, 2025



UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Department of Computer Science

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**

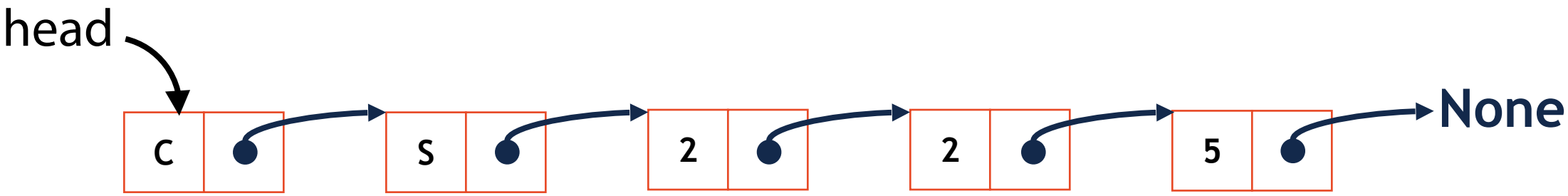
The list can be of a **fixed size** or is **resizable**

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

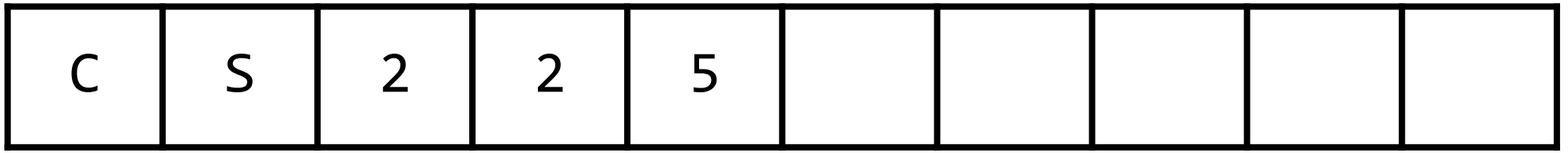
1. Insert
2. Delete
3. isEmpty
4. getData
5. Create an empty list

List Implementations

1. Linked List

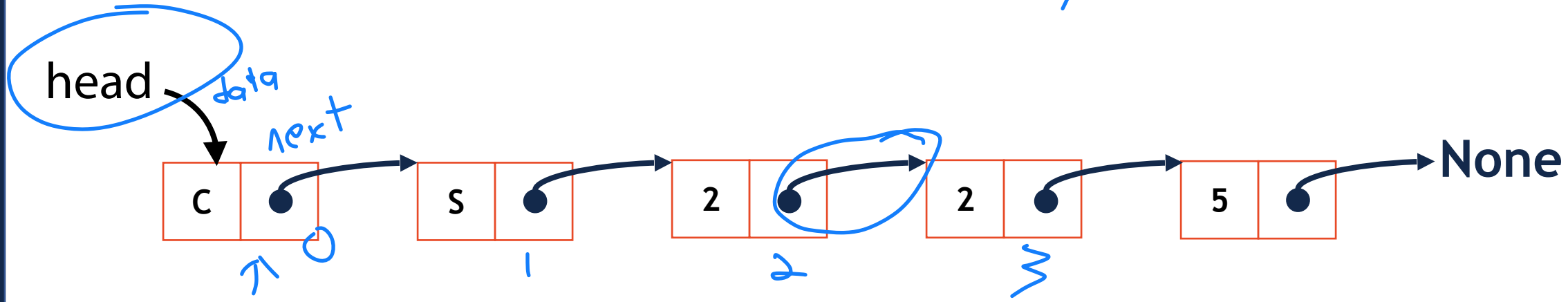


2. Array List



Where we left off…

Insert(X, 3)



1. Singly linked list only accesses forward —>

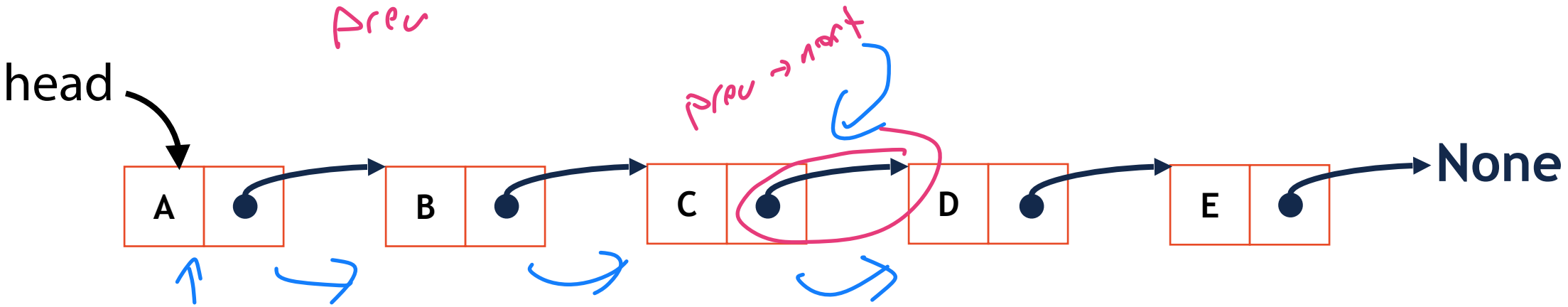
↳ Every node only knows one other node (next)

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

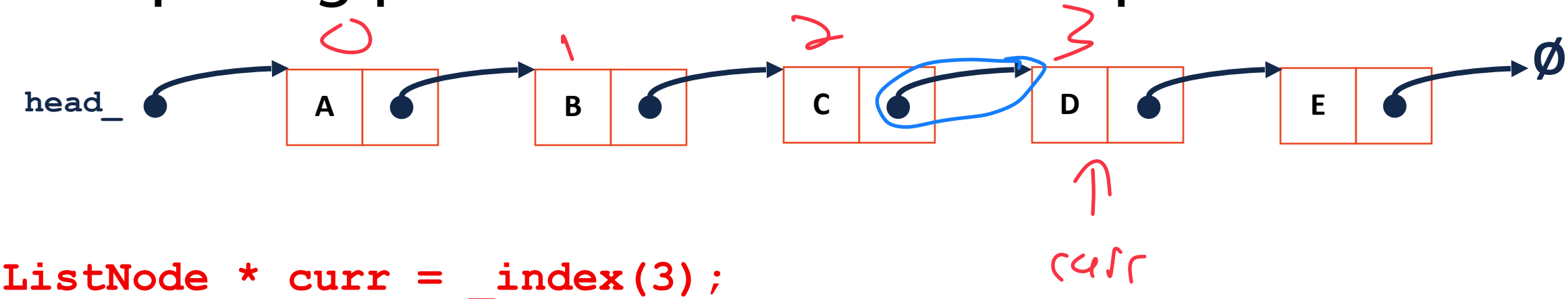
↳ The previous node's next

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);
```

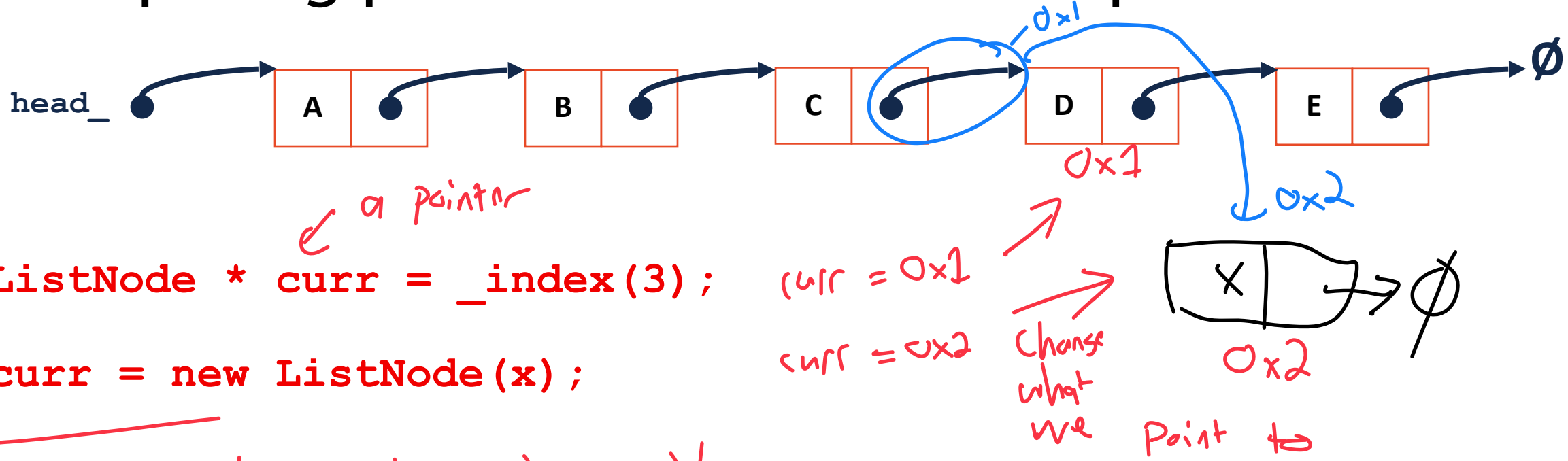
We can access `curr->data` and `curr->next` but not `previous.next`

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

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

`curr == previous.next`

Comparing pointer to reference-to-pointer

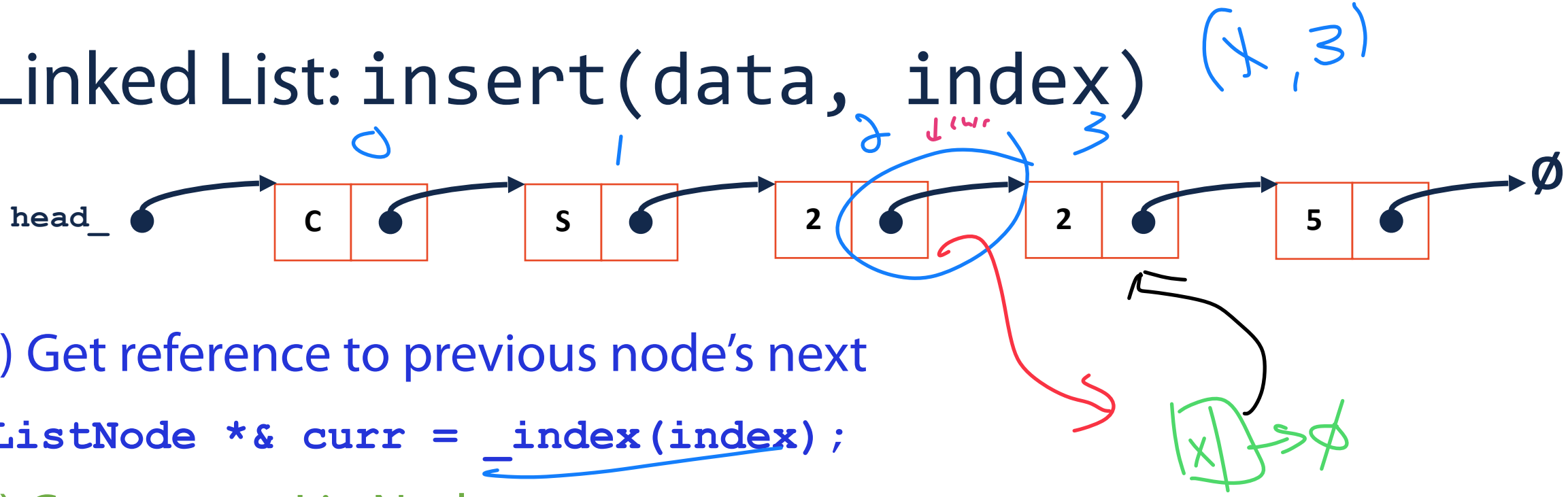



```
ListNode * curr = _index(3);

curr = new ListNode(x);
```

List not changed!

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

curr = new ListNode(x);
```

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;
```

ListNode(data, curr)

4) Modify the previous node to point to new ListNode

```
curr = tmp;
```

this is prev->next

curr->next

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
```

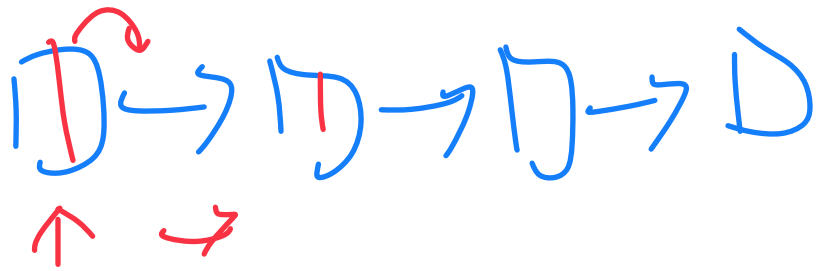
List.hpp

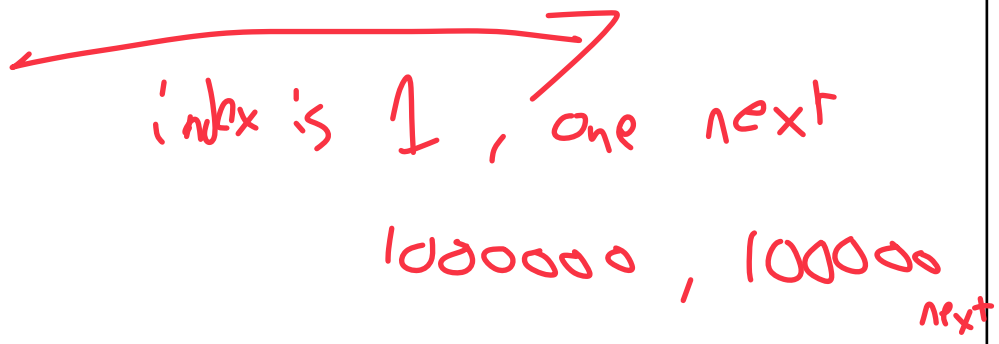
```
1
2  template <typename T>
3  void List<T>::insert(const T & data,
4  unsigned index) {
5
6
7
8    ListNode *& curr = _index(index);
9
10
11
12   ListNode * tmp = new ListNode(data);
13
14
15
16   tmp->next = curr;
17
18
19
20   curr = tmp;
21 }
22
```

What is the Big O of ~~insert~~?

O(1) | O(n)

where n is length of list





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 [ ]

getData()

template <typename T>

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

↳ get value

x = V[1];

↳ set value

V[1] = 10;

copy of orig value

T blackbox() {

}

ref to orig value

T & refBox () {

}

What return type should this function have?

T &

other function

X = blackbox()

x = 10

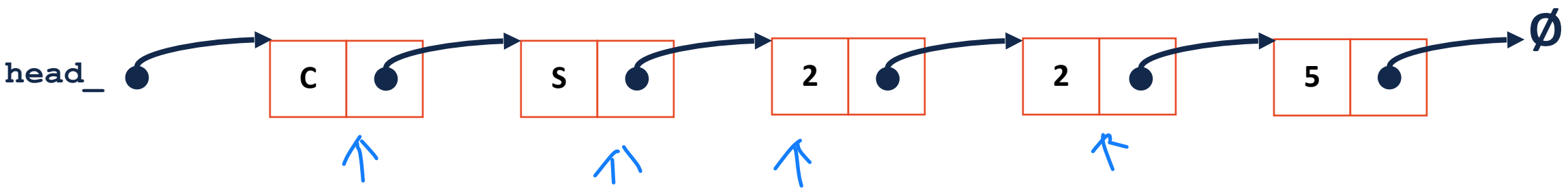
Y = refbox()

Y = 15

List.hpp

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

ListNode
data | next
T* LN*

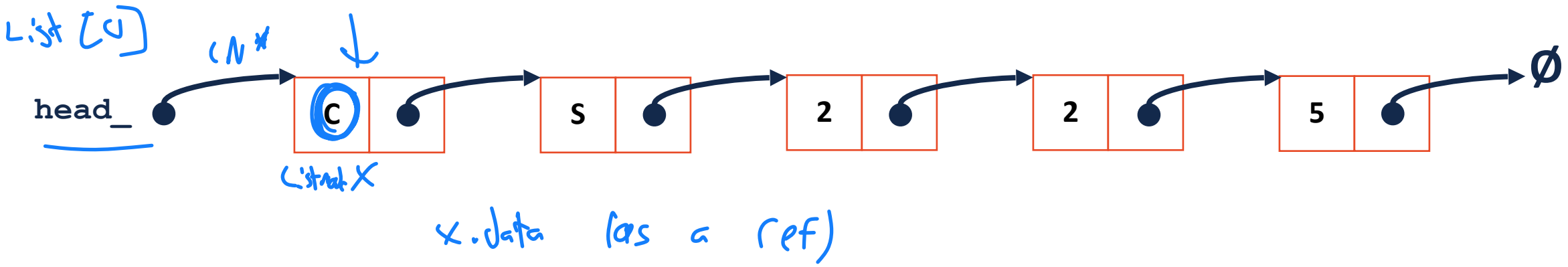


*tmp ∈ ListNode

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



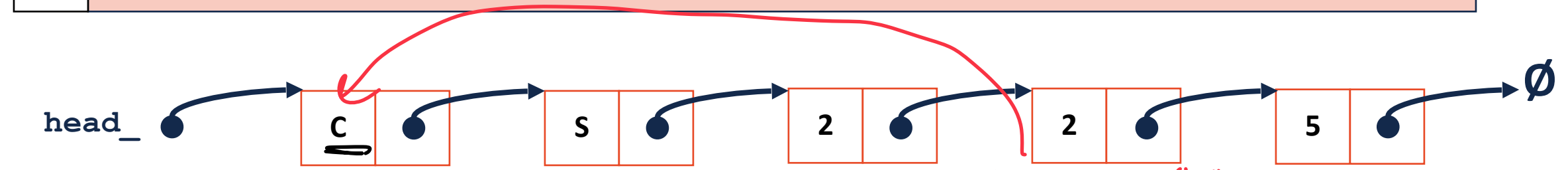
What is the Big O of random access?

List.hpp

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

```
add (int a, int b)
  a = 10 // local change

add (int &a, int &b)
  a = 10 // changes
main
add (x, y)   ← same input
add (x, y)
```

Diff input !!



x = List[0] // this is a copy of the content here "C"

List[0] = 10; "C" = 10; ← cannot set value of literal

What is the Big O of random access?

Linked List: remove(<parameters>)

What input parameters make sense for remove?

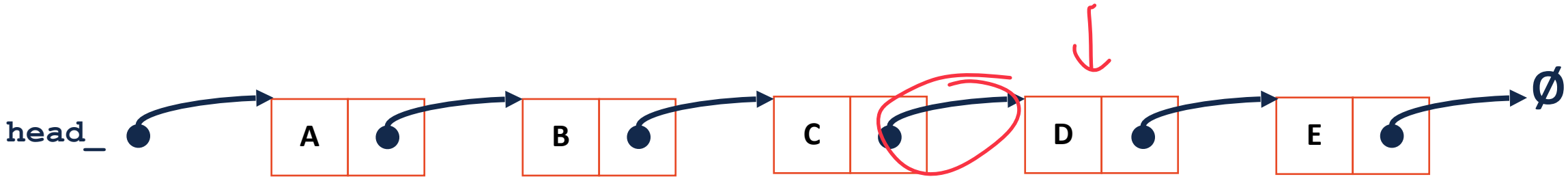
↳ unsigned index

↳ A specific node (is a ref to a pointer)

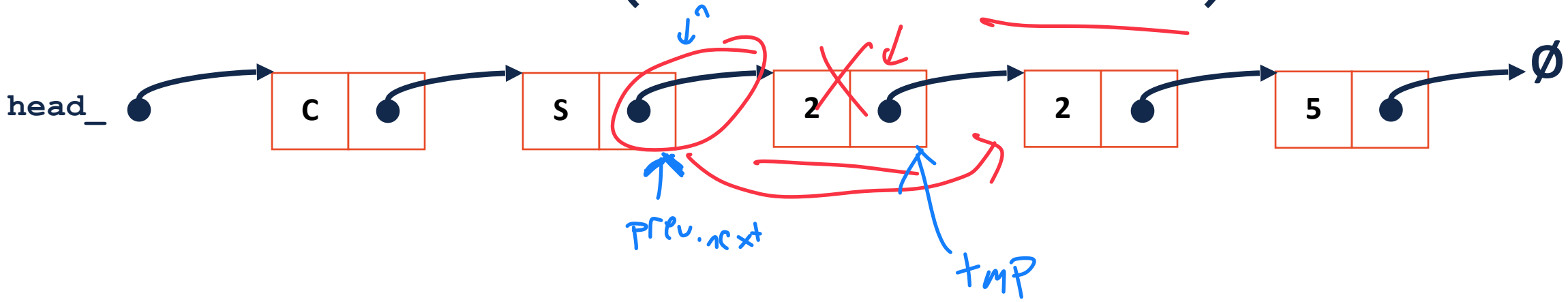
List Node *&

↳ A value

↳ Remove "E"



Linked List: remove(ListNode *& n)



ListNode *tmp = n; (1)

n = n->next;

delete tmp;

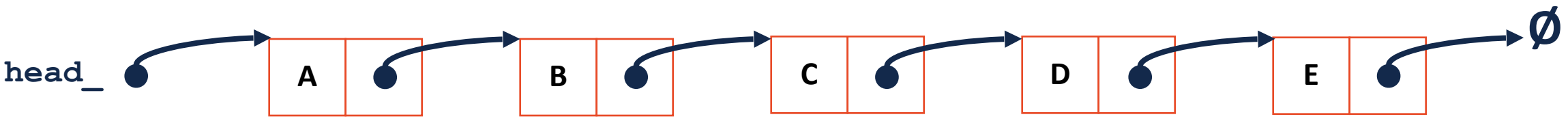
List.hpp

```
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  }
```

← a copy!

Pass by value b/c we delete the original and copy is on Stark

after-class question

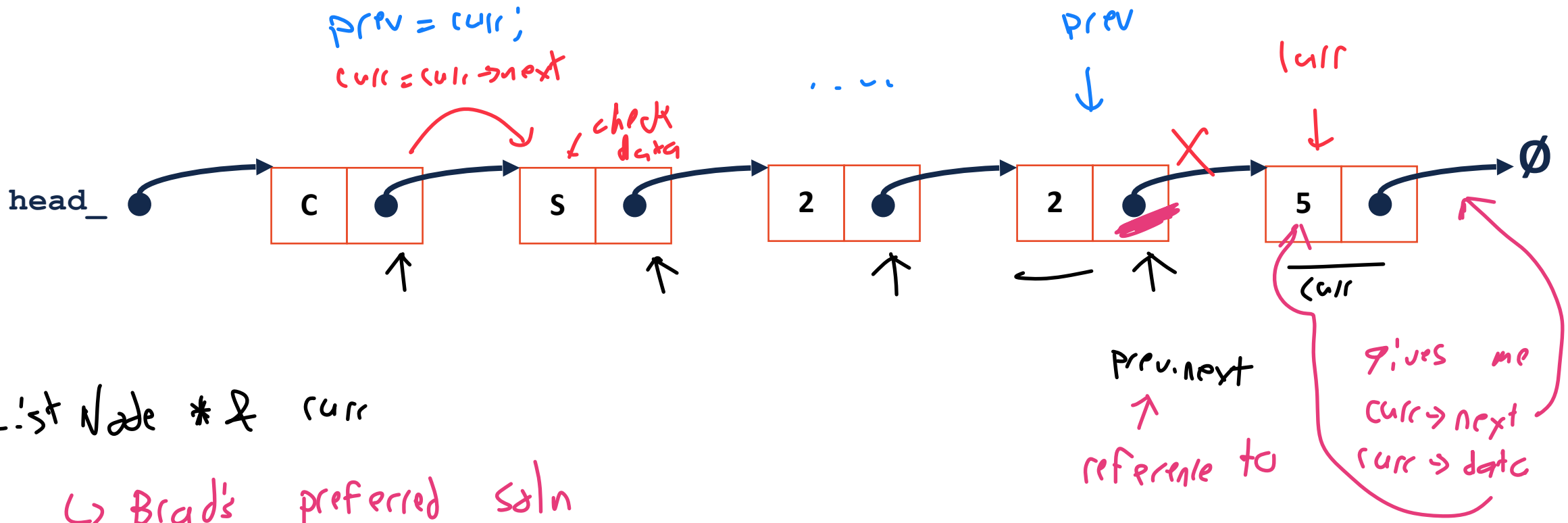


Linked List: remove(T & data)

remove(5)

LinkedList * prev

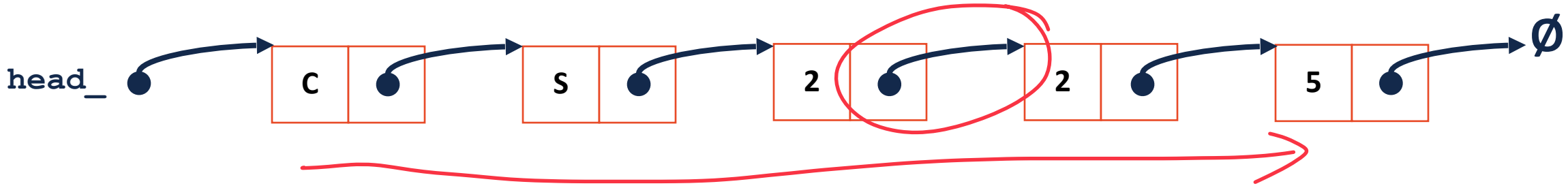
LinkedList * curr



ListNode *& curr

↳ Brad's preferred soln

Linked List: `remove`



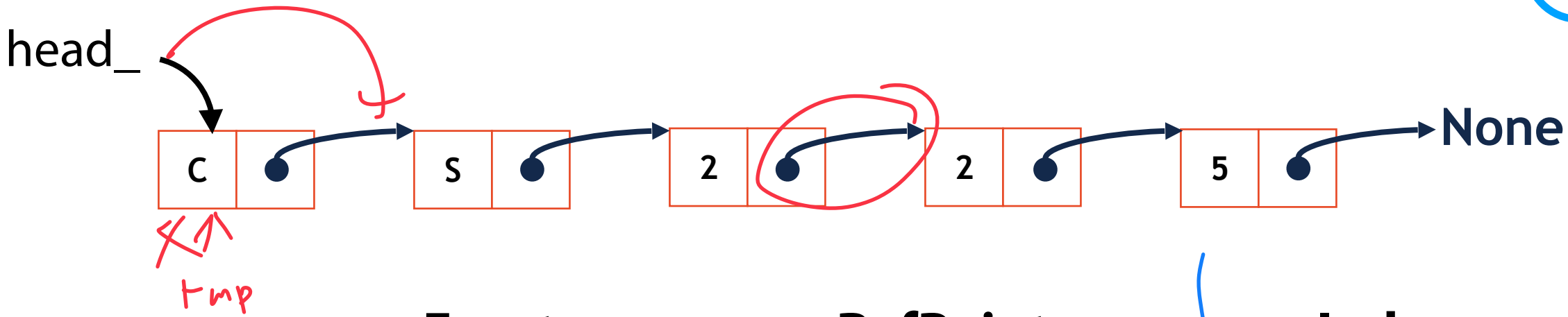
Running time for `remove(ListNode *&)`

O(1)

Running time for `remove(T & data)` or index

O(n)

Linked List Runtimes



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

b/c find/random access is O(n)

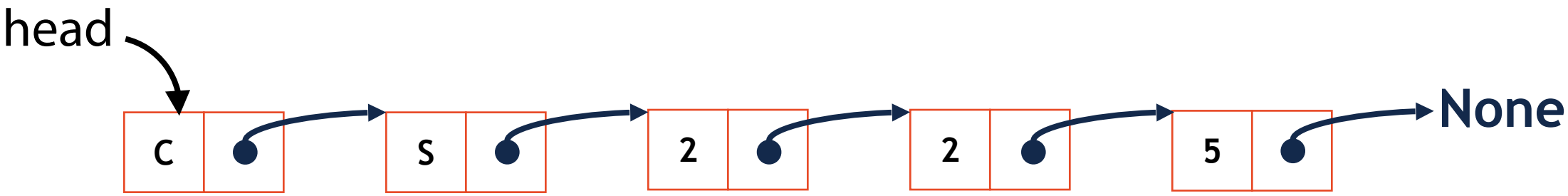
Thinking critically about linked lists…

What common list use case lets us take advantage of O(1) edits?

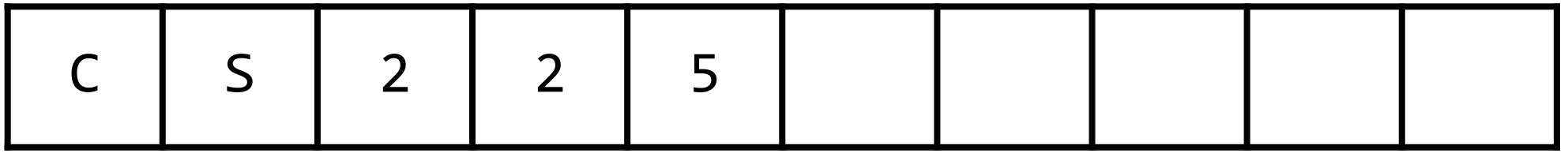
What is the runtime to find an item of interest?

List Implementations

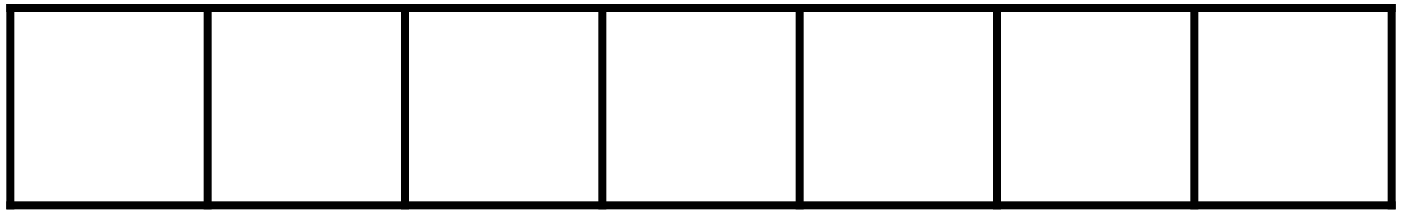
1. Linked List



2. Array List



Array List



An array is allocated as continuous memory.

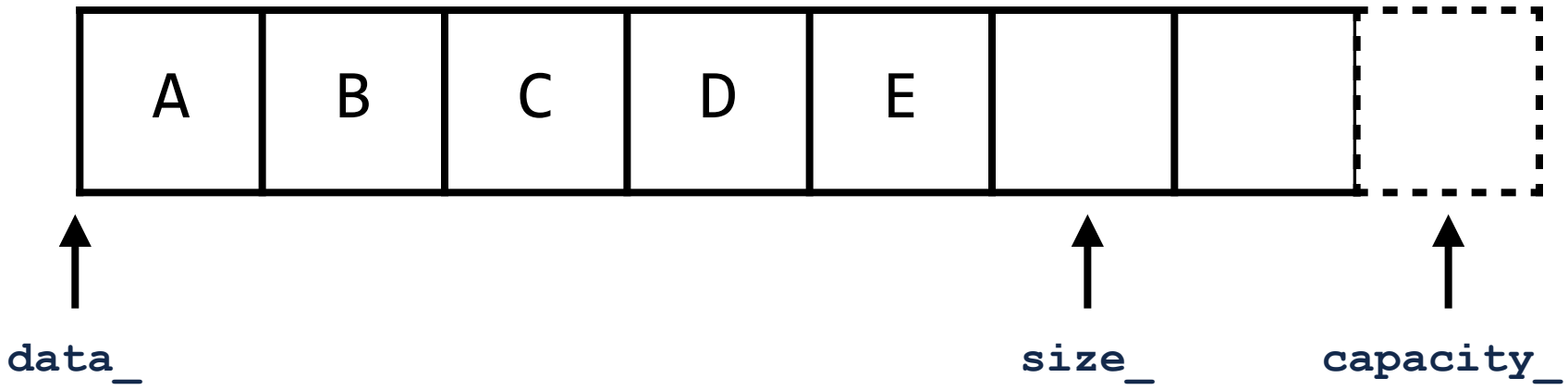
Three values are necessary for efficient array usage:

1)

2)

3)

Array List



In C++, vector is implemented as:

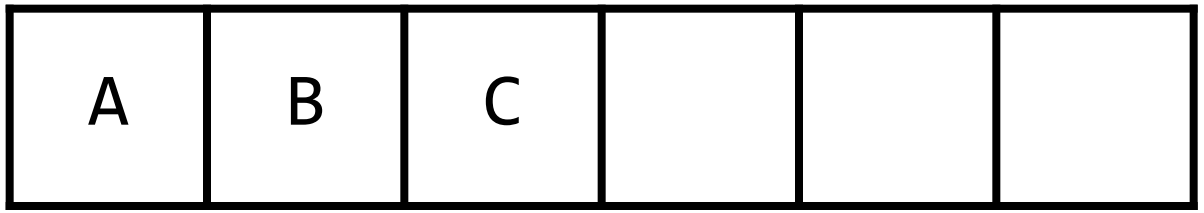
1) **Data:** Stored as a pointer to array start

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

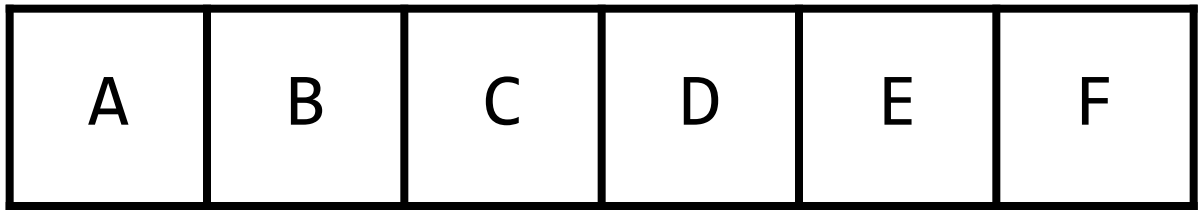
```
 1  #pragma once
 2
 3  template <typename T>
 4  class List {
 5  public:
…       /* --- */
25  private:
26    T *data_;
27
28    T *size_;
29
30    T *capacity_;
…
        /* --- */
    };
```



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

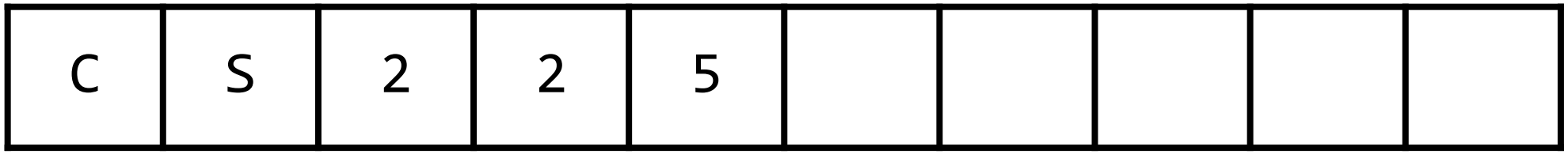
List.h

```
 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_;
 …
        /* --- */
    };
```

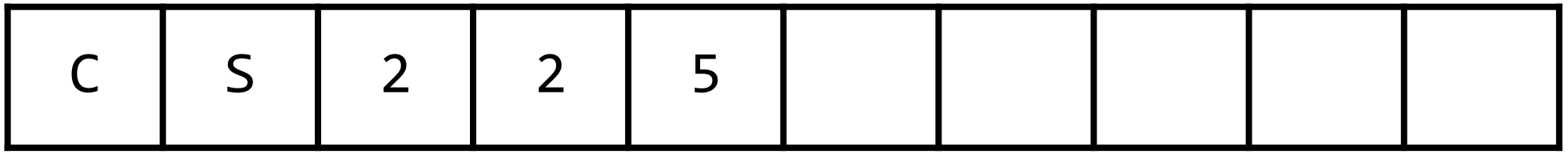


How do I know if I'm at capacity?

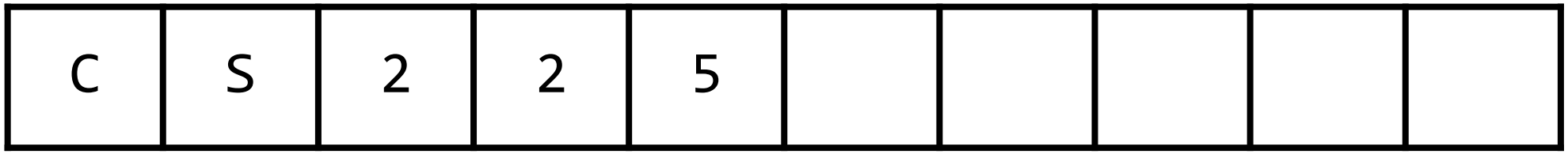
Array List: [ ]



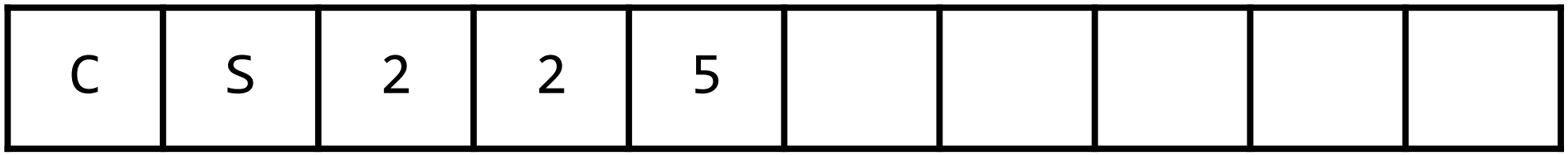
Array List: `insertFront(data)`



Array List: `insertBack(data)`



Array List: `insert(data, index)`



Array List: addspace(data)