CMSC 341
Lecture 7 Lists

Today's Topics

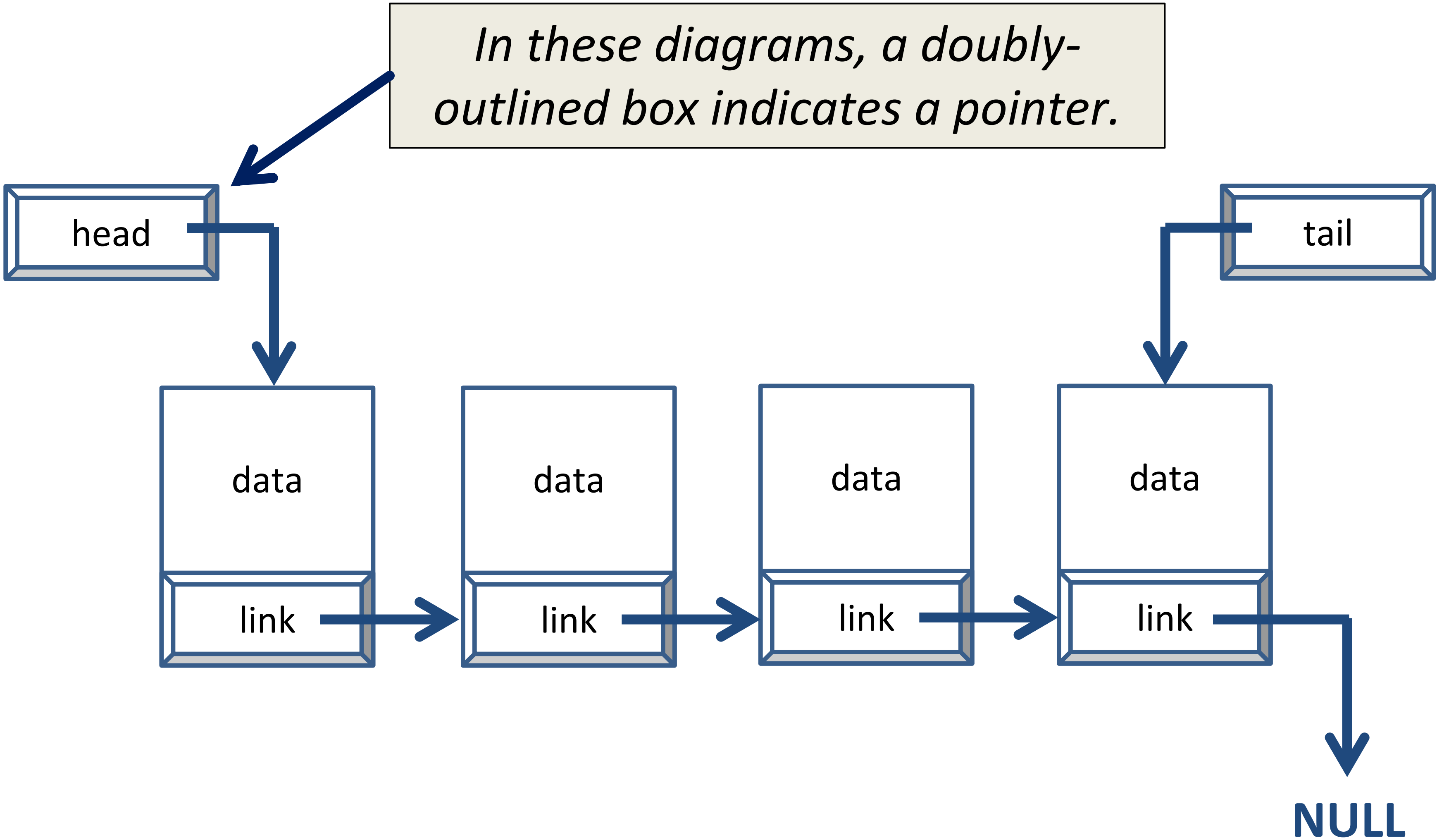
- Linked Lists
  - vs Arrays
  - Nodes
- Using Linked Lists
  - "Supporting Actors" (member variables)
  - Overview
  - Creation
  - Traversal
  - Deletion

Linked Lists vs Arrays

What is a Linked List?

- Data structure
  - Dynamic
  - Allow easy insertion and deletion
- Uses nodes that contain
  - Data
  - Pointer to next node in the list

Example Linked List

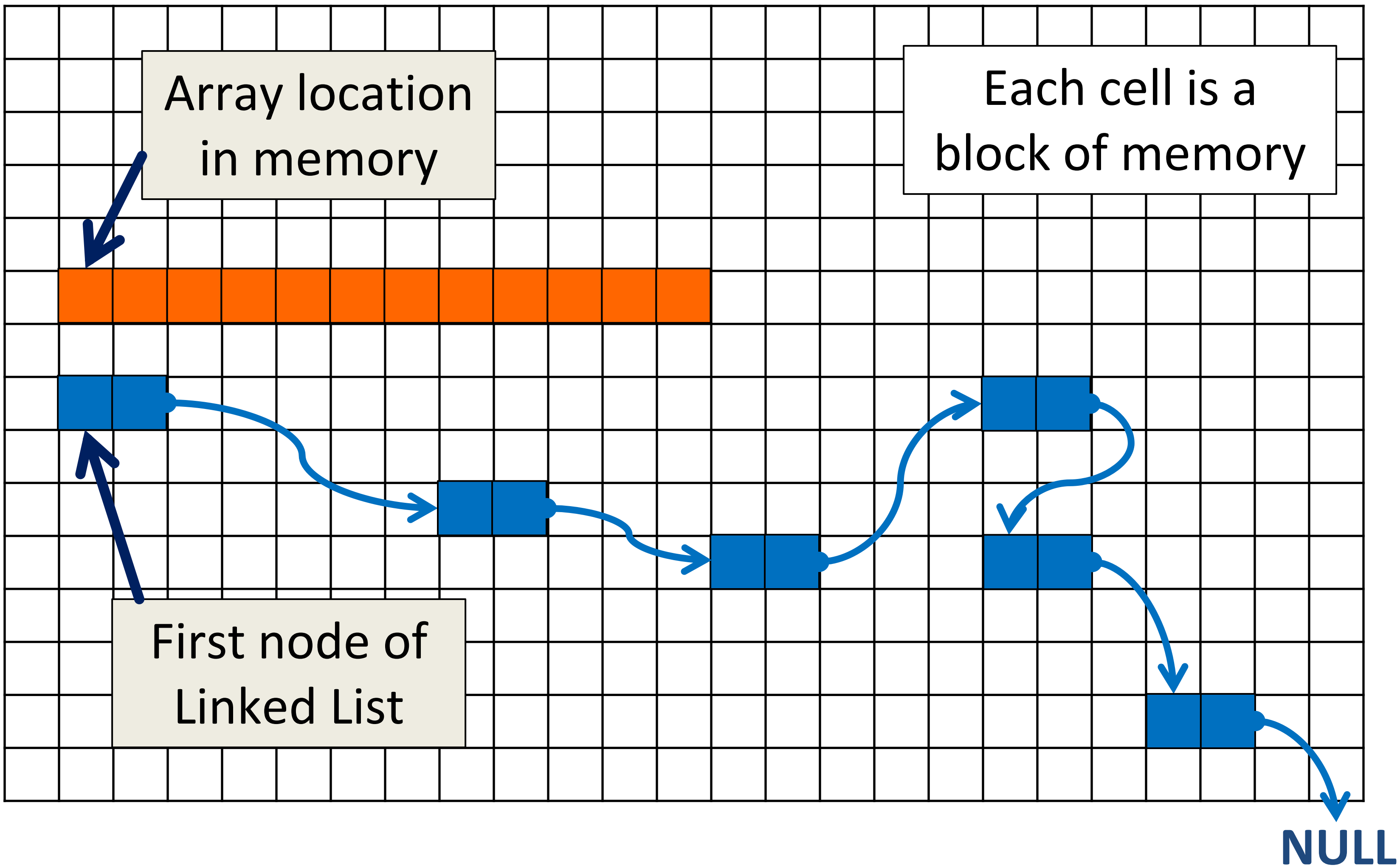


Why Use Linked Lists?

- We already have arrays!

- What are some disadvantages of an array?
  - Size is fixed once created
  - Inserting in the middle of an array takes time
  - Deletion as well
  - Sorting
  - Requires a *contiguous* block of memory

Arrays vs Linked Lists in Memory



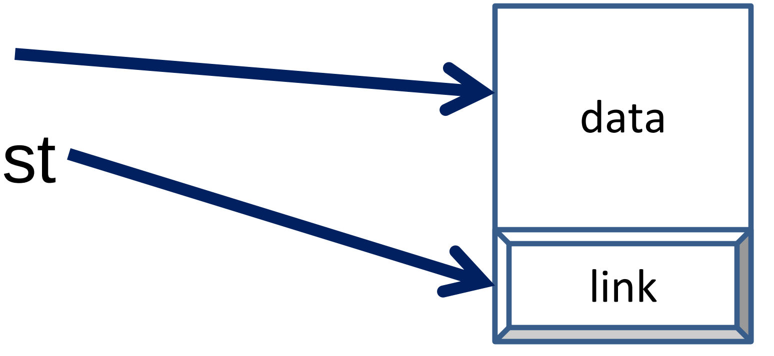
(Dis)Advantages of Linked Lists

- Advantages:
  - Change size easily and constantly
  - Insertion and deletion can easily happen anywhere in the Linked List
  - Only one node needs to be contiguously stored
- Disadvantages:
  - Can’t access by index value
  - Requires management of memory
  - Pointer to next node takes up more memory

Nodes

Nodes

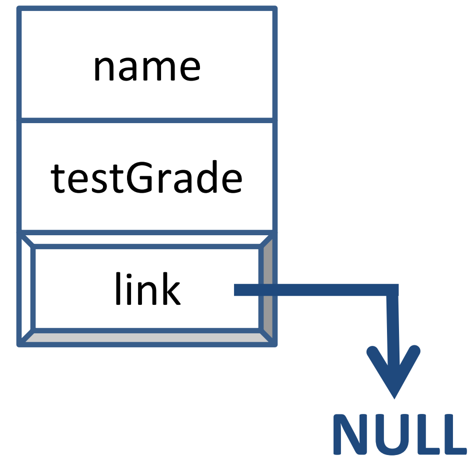
- A node is one element of a Linked List
- Nodes consist of two main parts:
  - Data stored in the node
  - Pointer to next node in list



- Often represented as structs

Code for Node Structure

```
struct Node
{
    String name;
    int    testGrade;
    Node   *link;

    // constructor
    // accessors
    // mutators
};
```



link can point to other nodes

two options:
1. another Node
2. NULL

“Supporting Actors” of Linked Lists (Member Variables)

“Supporting Actors” of a Linked List

- Five member variables used to create and keep track of a Linked List
  - All five variables are **private** members
  - All of them are pointers to a Node

  - **`FRONT`** (or **`HEAD`**) points to front of list
  - **`REAR`** (or **`TAIL`**) points to end of list
  - **`INSERT`** used in node creation
  - **`CURR`** (or **`CURSOR`**) used to “traverse” list
  - **`PREVIOUS`** used to “traverse” list

The **FRONT** Node Pointer

- **FRONT** points to the very first node in the Linked List

- What if the Linked List is empty?
  - Points to NULL

The **REAR** Node Pointer

- **REAR** points to the very last item in the Linked List
  - Useful when inserting nodes at the end
- What if there is only one item in the Linked List?
  - Points to the same item as **FRONT**
- What if the Linked List is empty?
  - Points to NULL

The **INSERT** Node Pointer

- **INSERT** is used when we are creating and inserting a new node into the Linked List

```
INSERT = new Node;
```

- We'll see an example of this soon

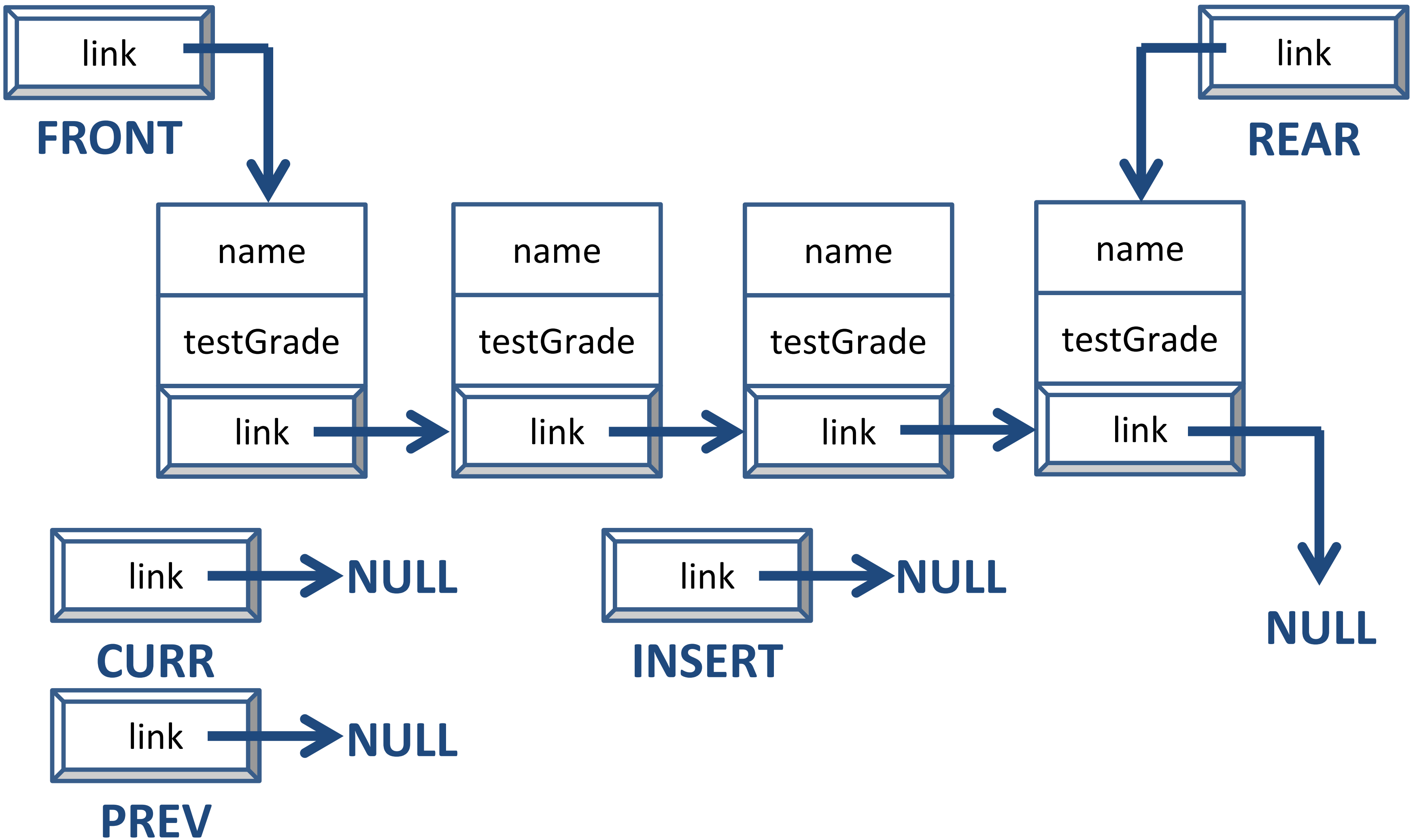
The **CURR** and **PREV** Node Pointers

- The **CURR** and **PREV** node pointers are used to “traverse” or travel down the length of a Linked List

- Why do we need two nodes to do this?

Linked List Overview

Example Linked List (Again)



Important Points to Remember

- Last node in the Linked List points to **`NULL`**
- Each node points to either another node in the Linked List, or to **`NULL`**
  - Only one link per node
- **`FRONT`** and **`REAR`** point to the first and last nodes of the Linked List, respectively

Managing Memory with Linked Lists

- Hard part of using Linked Lists is ensuring that none of the nodes go “missing”
- Think of Linked List as a train
  - (Or as a conga line of Kindergarteners)
- Must keep track of where links point to
- If you’re not careful, nodes can get lost in memory (you have no way to find them)

Linked List Functions

- What functions does a Linked List class implementation require?

- Linked_List constructor
  - Initialize all member variables to **`NULL`**
- **`insert()`**
- **`remove()`**
- **`printList()`**
- **`isEmpty()`**

Linked Lists' "Special" Cases

- Linked Lists often need to be handled differently under specific circumstances
  - Linked List is empty
  - Linked List has only one element
  - Linked List has multiple elements
  - Changing something with the first or last node
- Keep this in mind when you are coding

Creation of a Linked List

Creation of a New Linked List

- Call constructor

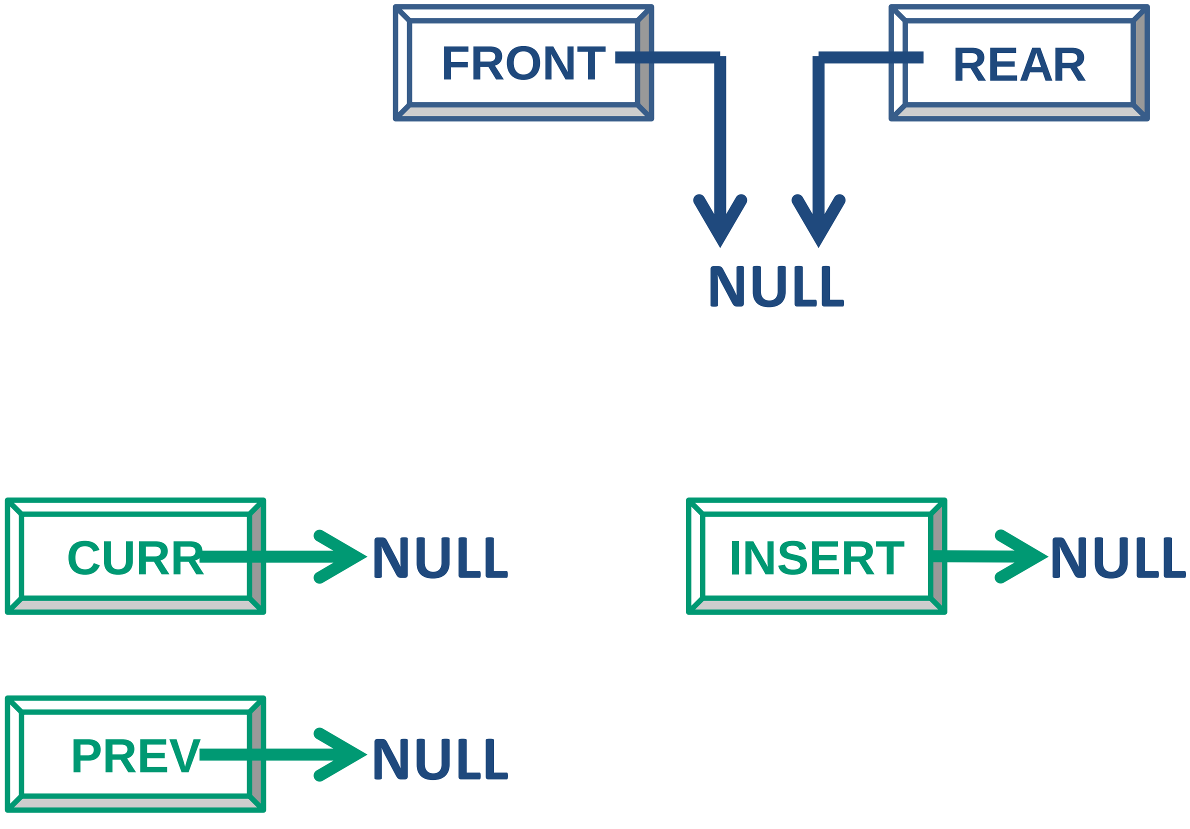
```
Linked_List test = new Linked_List();
```

- What does the constructor do?

```
// constructor definition
Linked_List() {
     FRONT  = NULL;
     REAR   = NULL;
     INSERT = NULL;
     CURR   = NULL;
     PREV   = NULL;
}
```

- Why are they all set to **`NULL`**?

Current State of Linked List `test`

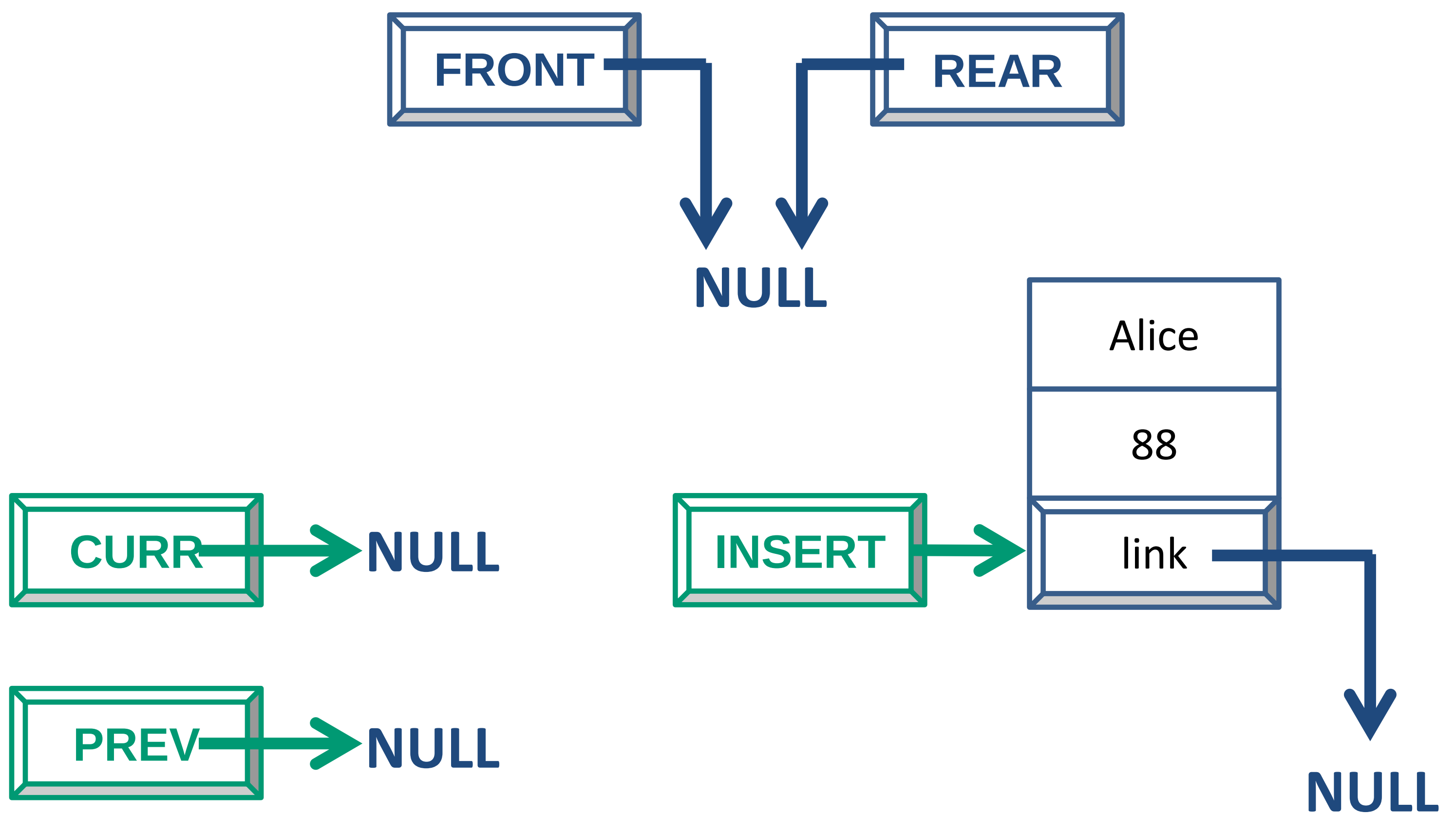


Inserting the First Node

- What do we do first?
  - Allocate space for the node, using **`INSERT`**
  - Initialize Node's data
  - Then what?
    - What are the two cases we care about?

```
void Linked_List::insert (String name, int score) {
    INSERT = new Node()
    // initialize data
    INSERT.setName (name);
    INSERT.setGrade(score);
    // what do we do?
```

Current State of Linked List `test`



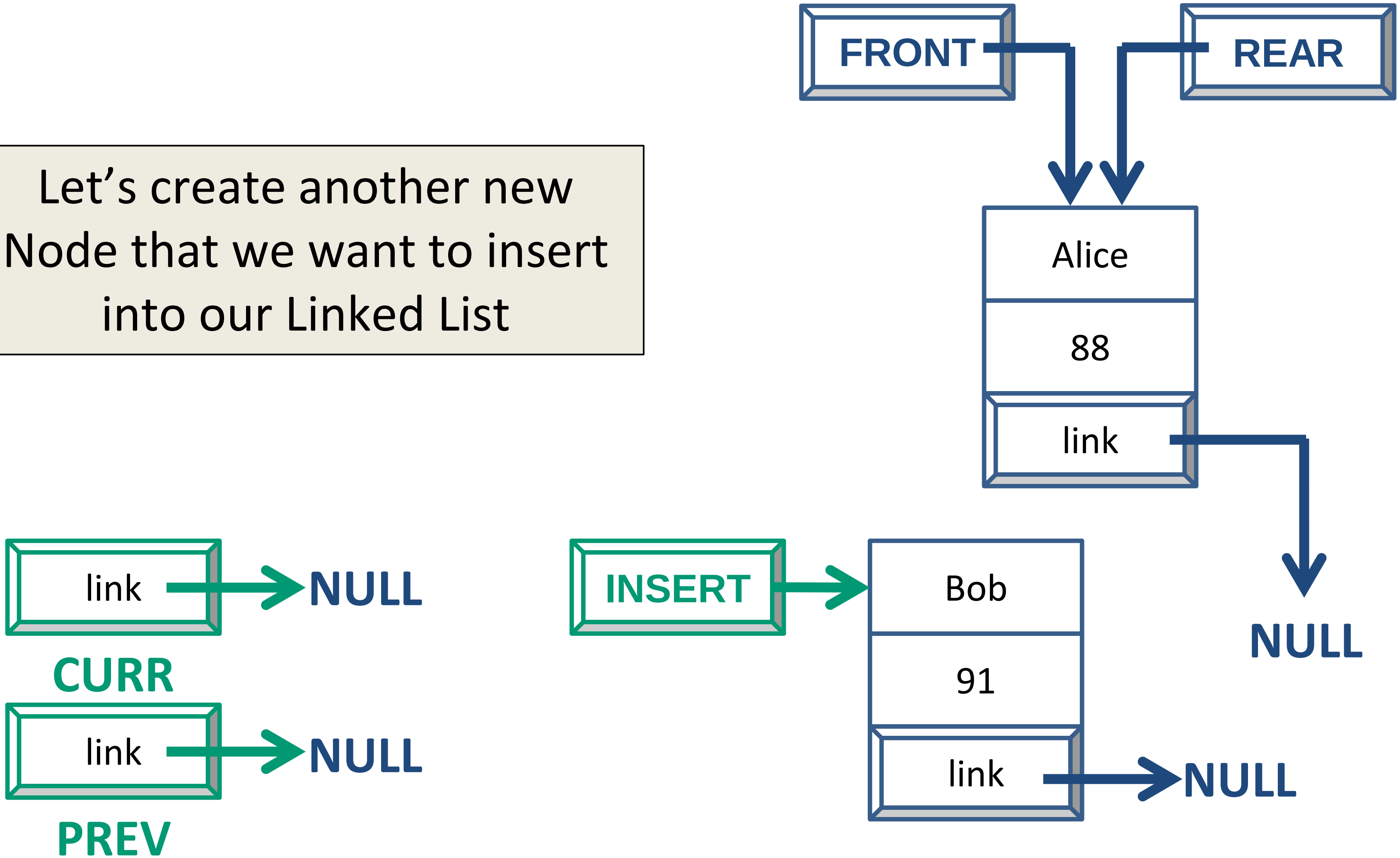
Insertion: Empty Linked List Case

- If the Linked List is empty, what do we do?
- **FRONT** and **REAR** point to the new Node
- What else should we do?

```
void Linked_List::insert (String name, int score) {
    // previous code...
    if ( isEmpty() ) {
        FRONT = INSERT;
        REAR  = INSERT;
    }
    INSERT = NULL;
}
```

Current State of Linked List `test`

Let's create another new Node that we want to insert into our Linked List

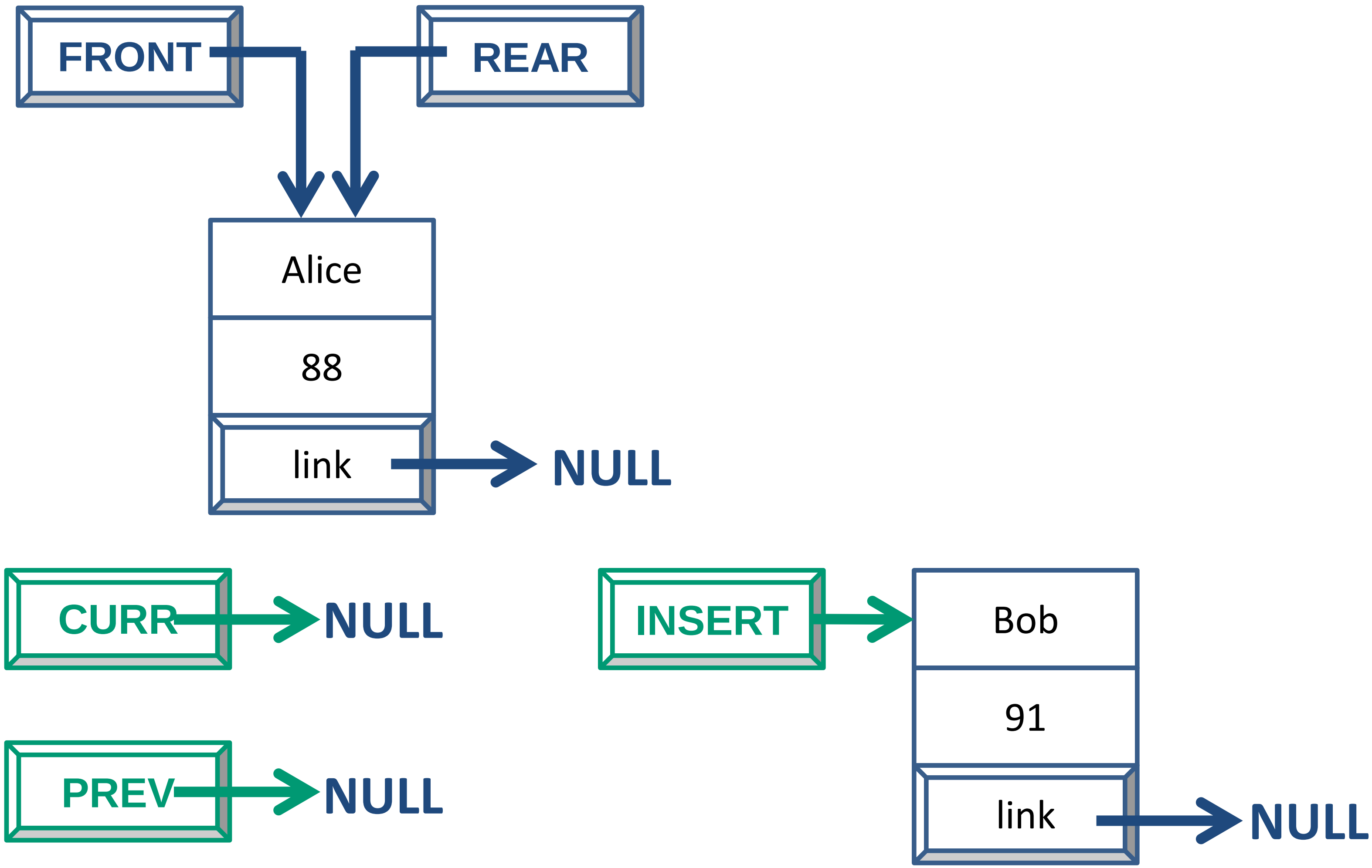


Insertion: Non-Empty Linked List Case

- Now that the Linked List is not empty, how does our insert() function change?
  - Let’s trace these changes

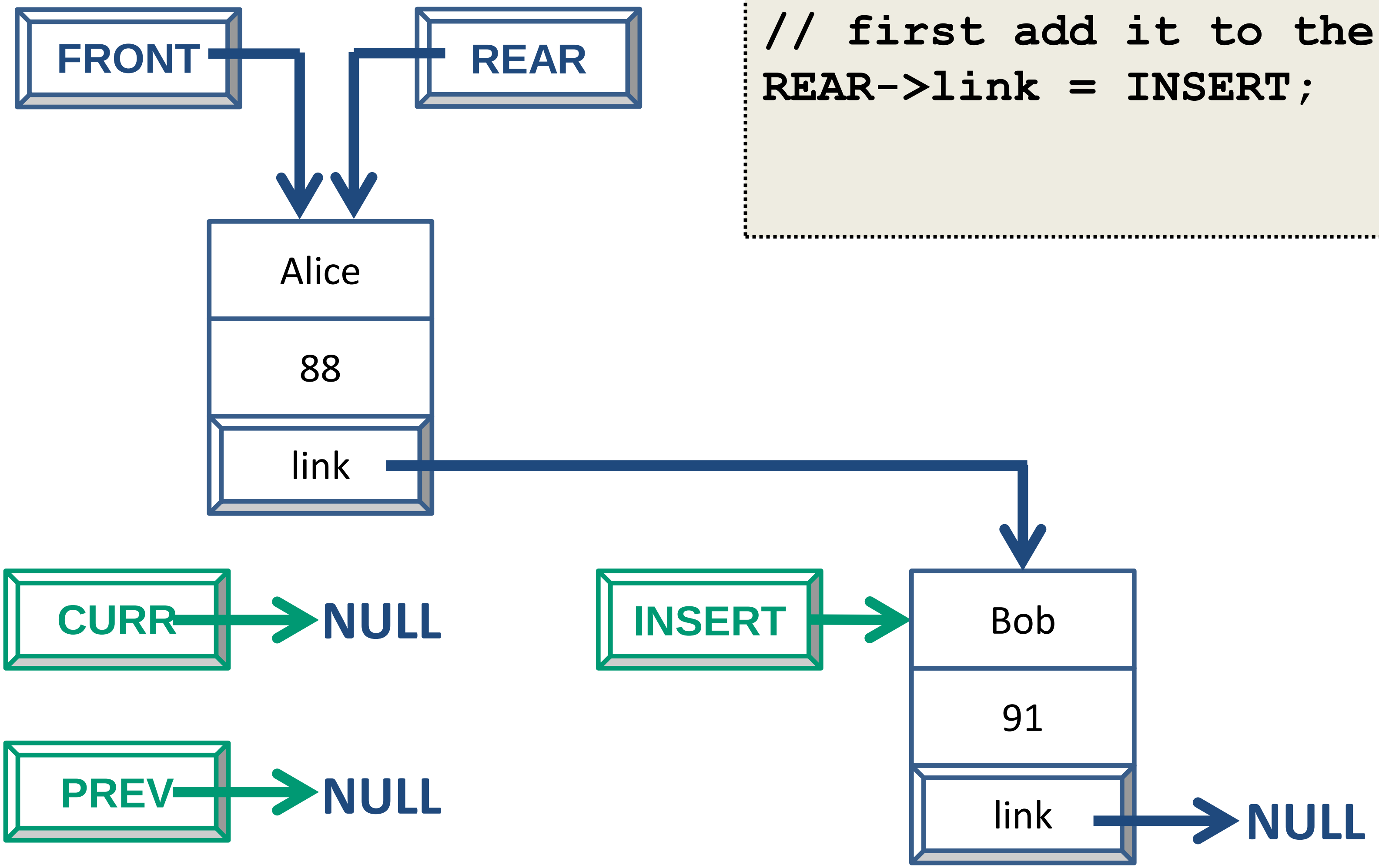
```
void Linked_List::insert (String name, int score) {
    ... // previous code for empty list
    else {
        // first add it to the end of the list
        REAR->link = INSERT;
        // then update REAR to point to the new last
        REAR = INSERT;
    }
    // rest of code...
```

Current State of Linked List `test`



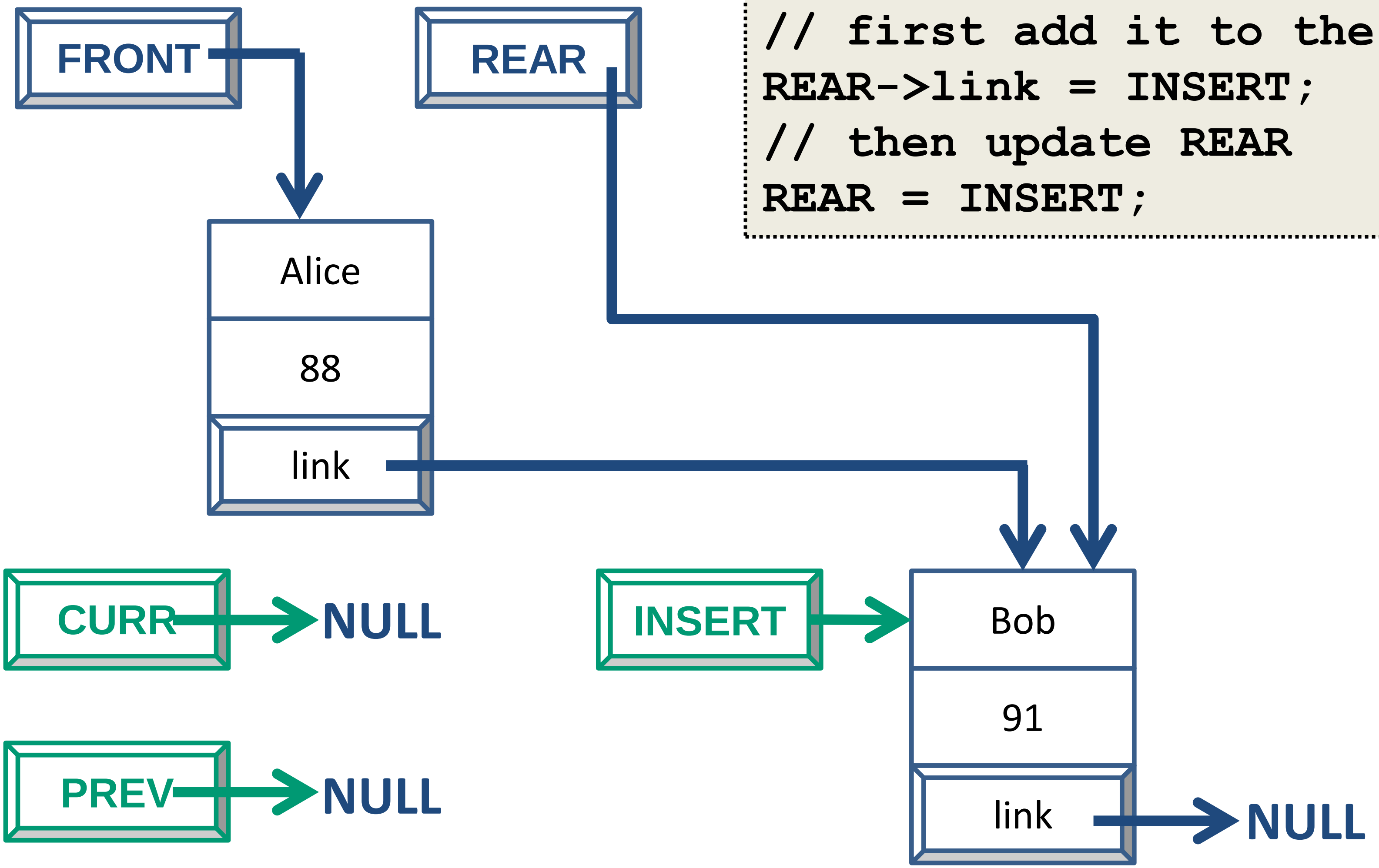
Current State of Linked List `test`

```
// first add it to the end
REAR->link = INSERT;
```



Current State of Linked List `test`

```
// first add it to the end
REAR->link = INSERT;
// then update REAR
REAR = INSERT;
```

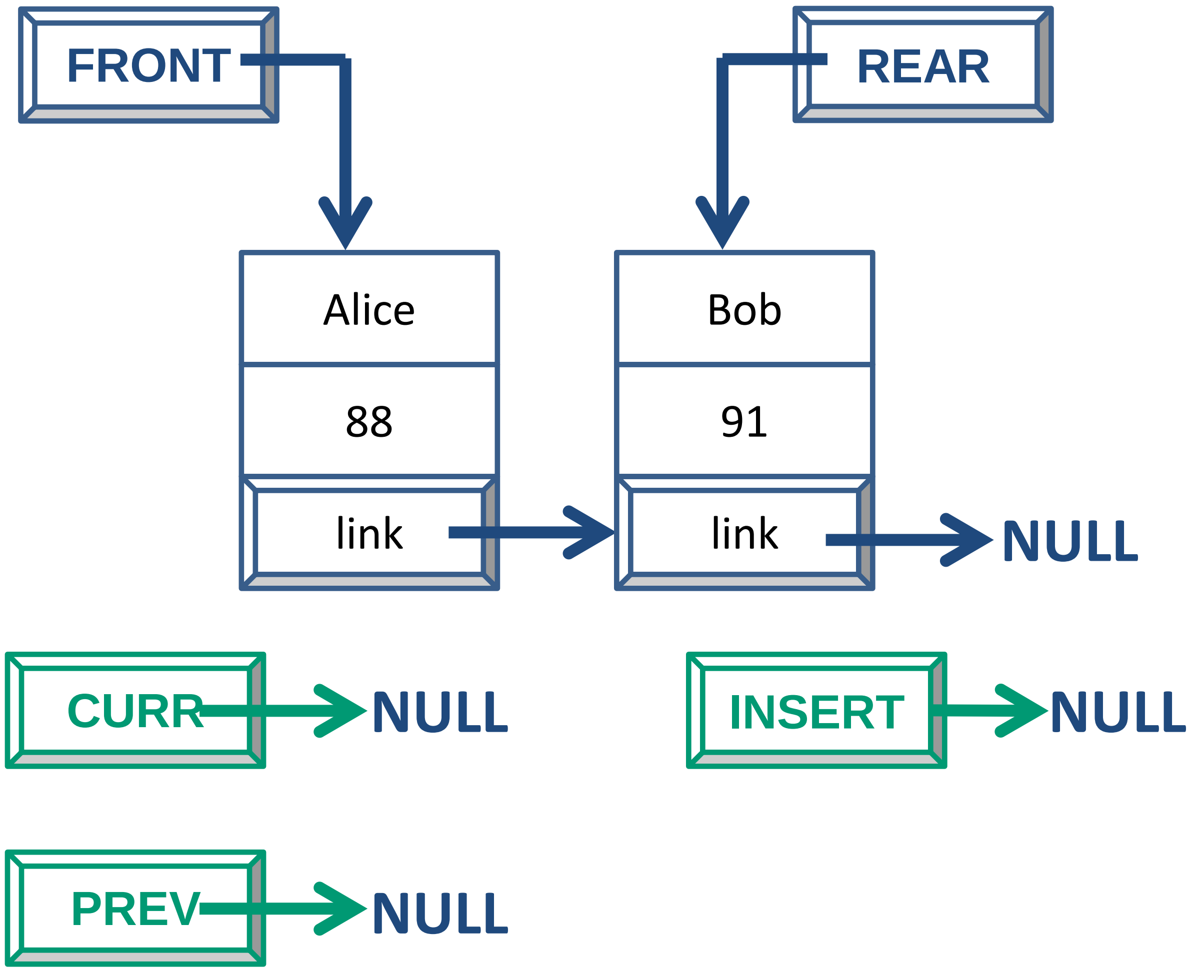


Final `insert()` Code

- Combine the REAR = INSERT from the if and else statements

```
void Linked_List::insert (String name, int score) {
    INSERT = new Node()
    // initialize data
    INSERT.setName (name);
    INSERT.setGrade(score);
    if ( isEmpty() ) {
        FRONT = INSERT;      // update for first item
    } else {
        REAR->link = INSERT; // add to end of list
    }
    REAR   = INSERT;         // update end of list
    INSERT = NULL;           // reset INSERT
}
```

Current State of Linked List `test`



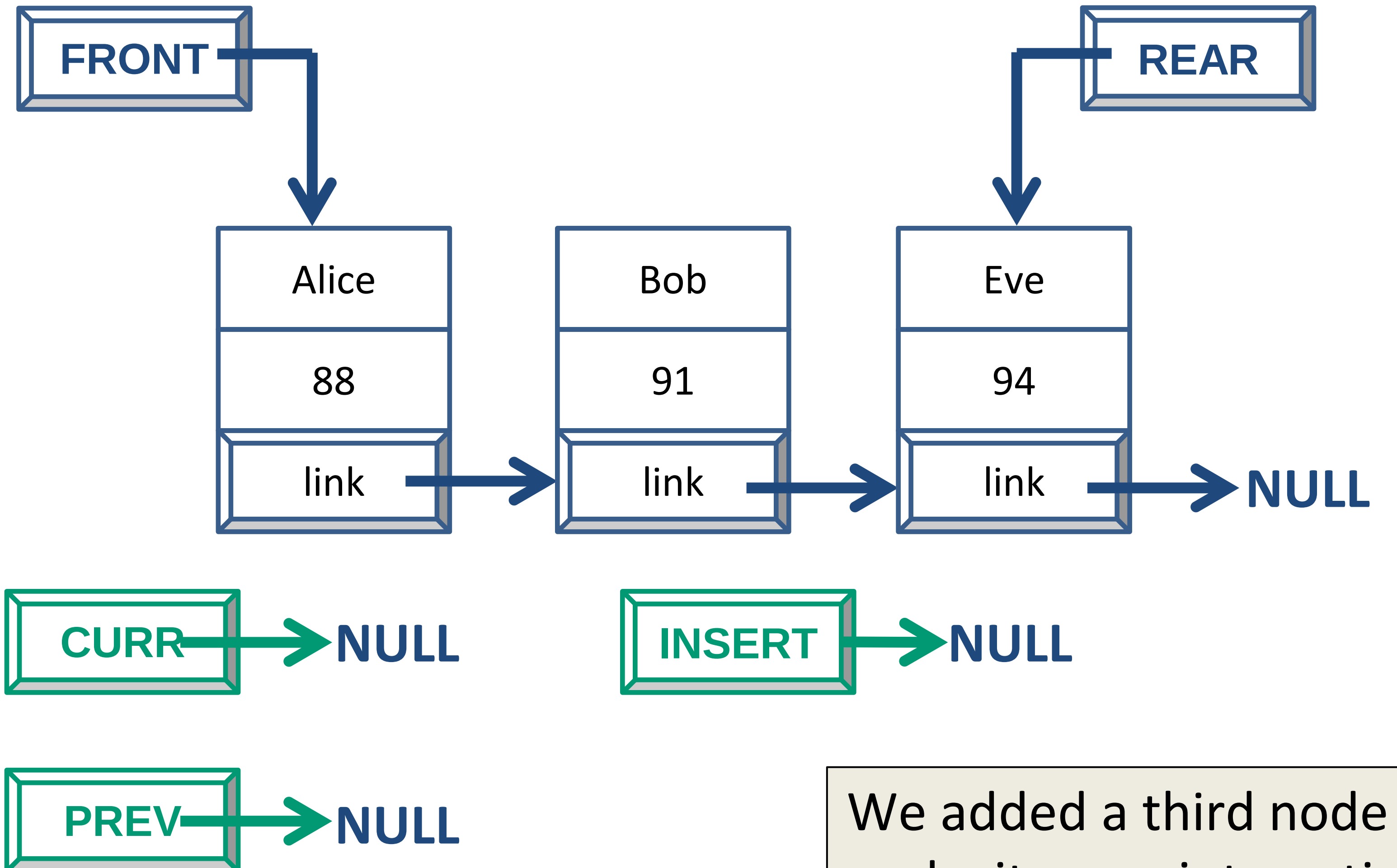
Traversal of a Linked List

Traversing the Linked List

- When would we need to traverse our list?
  - Printing out the contents
  - Searching for a specific node
  - Deleting a node
  - Counting the size of the list
    - (Better done with an updated member variable)

- We'll show the code for printing the list

Our Linked List Now



We added a third node to make it more interesting.

Before Traversing the Linked List

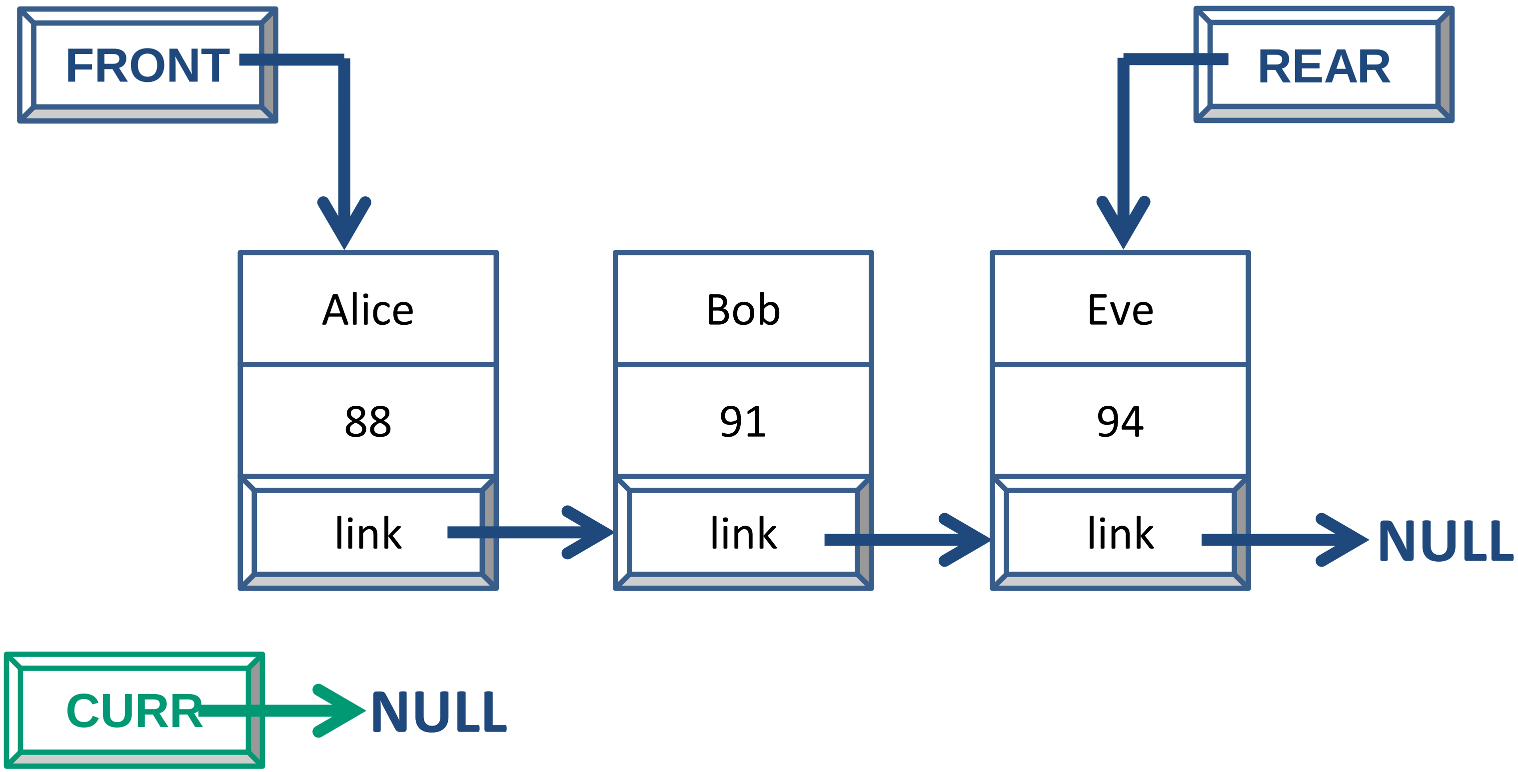
- What do we do first?
  - Check to see if the Linked List is empty
  - If it is, what should we do?
    - Print out a message
    - Return from the function

```
void Linked_List::printList() {
    if ( isEmpty() ) {
        cout << "This list is empty!";
        return;
    }
    // rest of the function
```

Planning out the Traversal

- If the Linked List is not empty, then we begin traversing the Linked List
  - How do we start?
  - How do we know when to stop?
  - How do we move from one node to another?
  - *Hint: Using* **`CURR`** *alone will work for this*
- Take a look at the diagram again, and think about the steps we need to take

Exercise: Traversing a Linked List



We don’t need **INSERT** or **PREV** to traverse the Linked List.

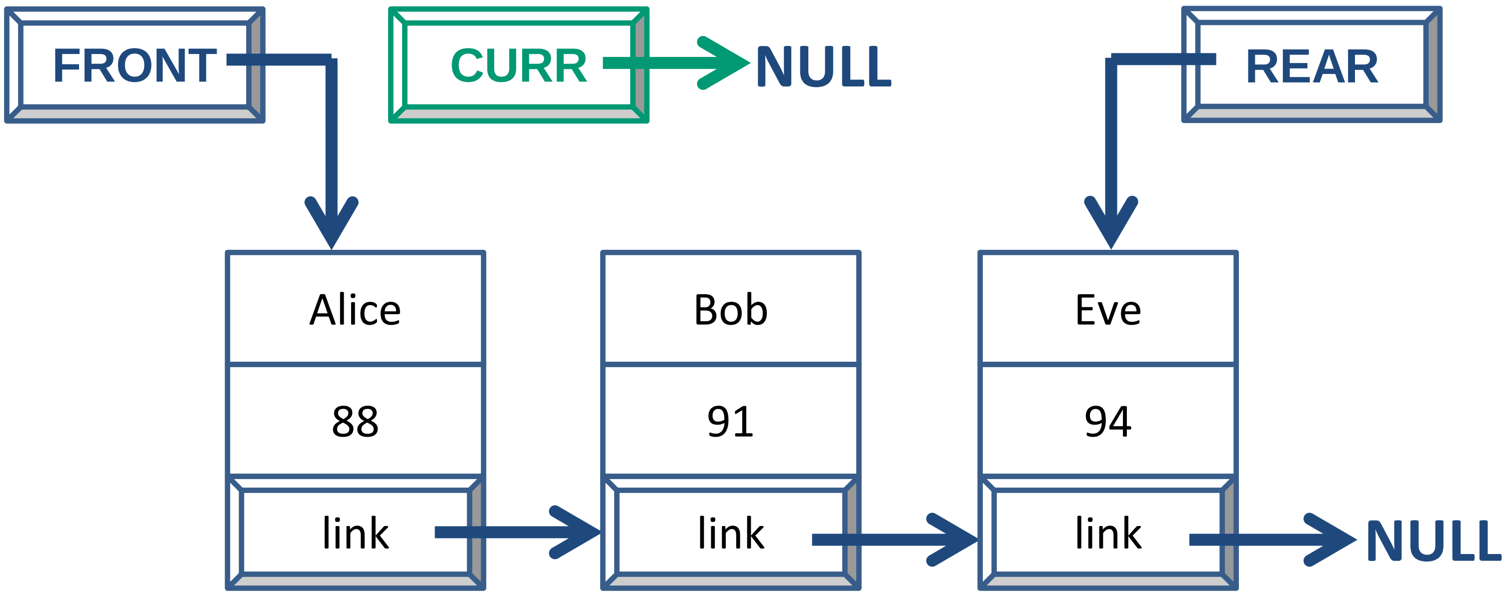
Traversing the List

- To control our traversal, we'll use a loop
  - Initialization, Termination Condition, Modification

1. Set **CURR** to the first node in the list
2. Continue until we hit the end of the list (**NULL**)
3. Move from one node to another (using **link**)

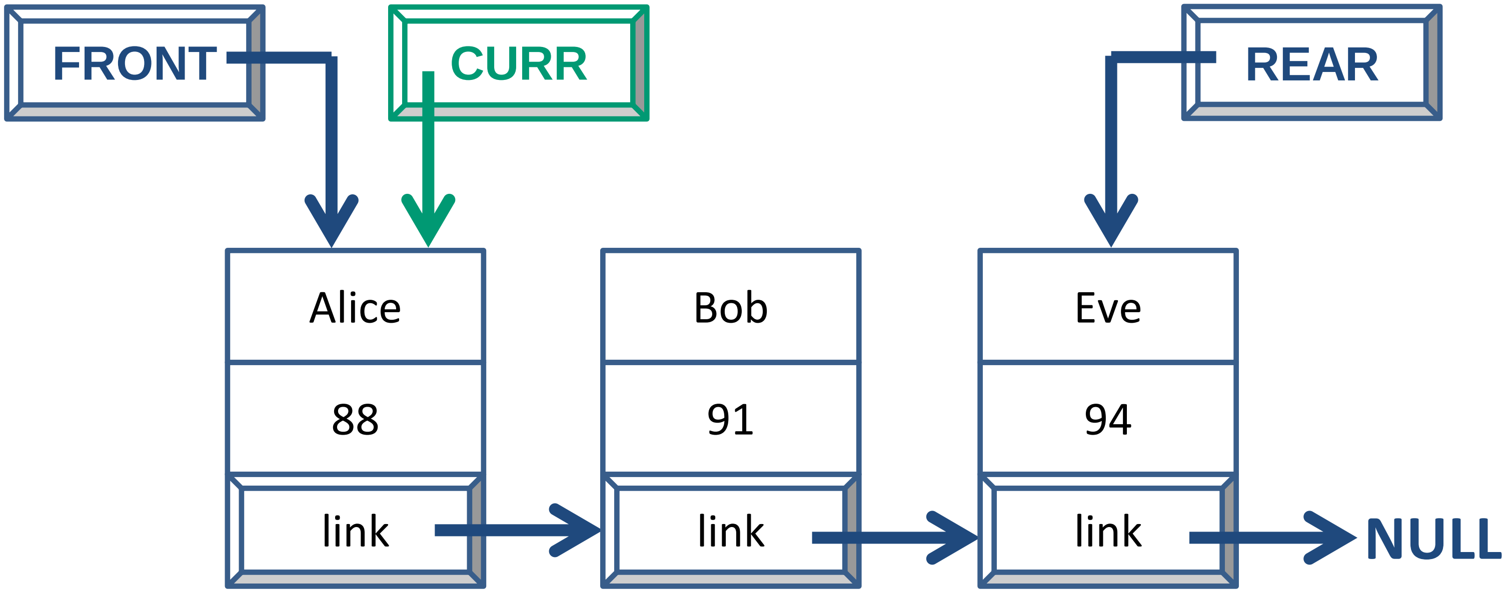
```
void Linked_List::printList() {
    // prev code (checking if empty)
    for (CURR = FRONT; CURR != NULL; CURR = CURR->link) {
        // print the information
        cout << "Name is "  << CURR->getName()  << endl;
        cout << "Grade is " << CURR->getGrade() << endl;
    }
```

Demonstration of Traversal



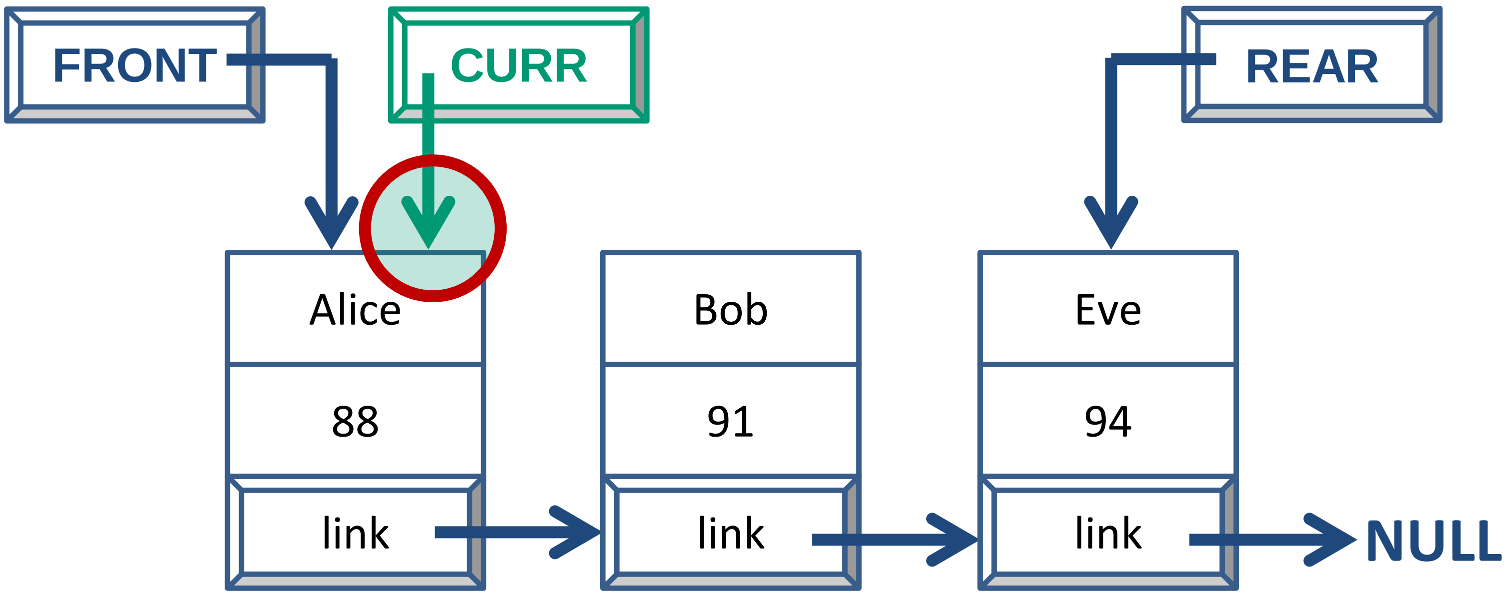

```
for (CURR = FRONT; CURR != NULL; CURR = CURR->link) {
```

Demonstration of Traversal




```
for (CURR = FRONT; CURR != NULL; CURR = CURR->link) {
```

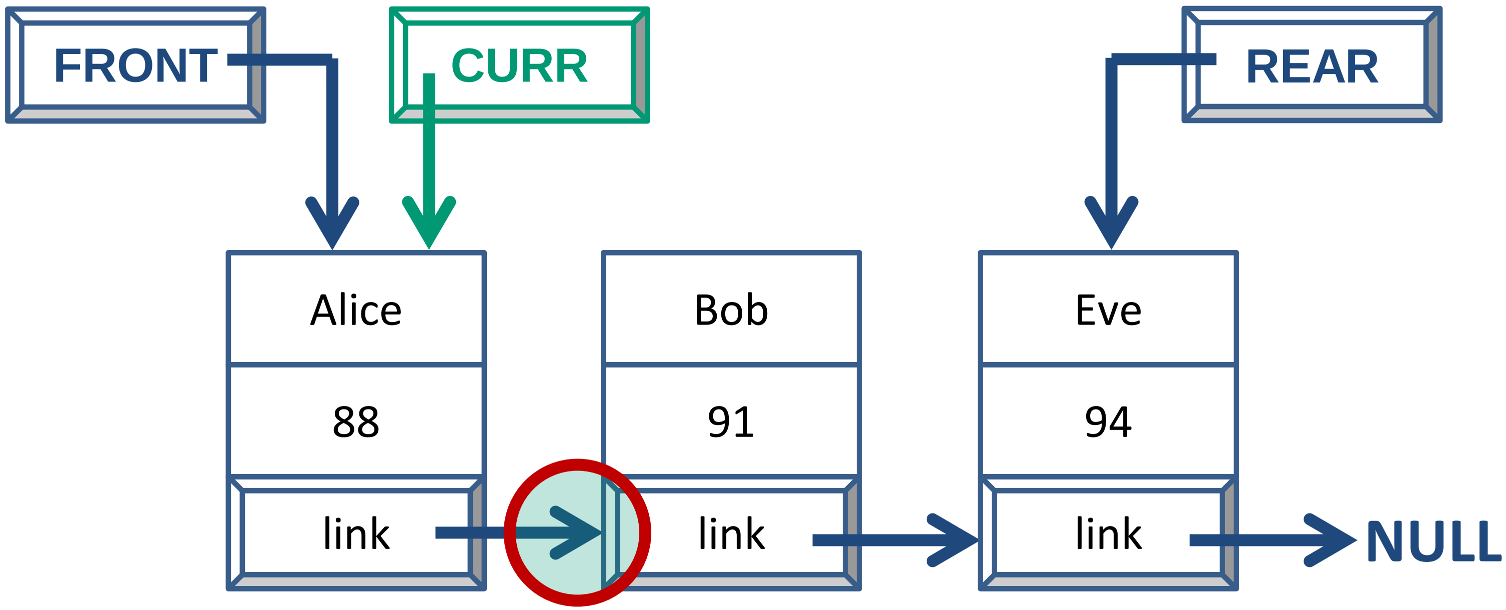
Demonstration of Traversal




```
for (CURR = FRONT; CURR != NULL; CURR = CURR->link) {
```

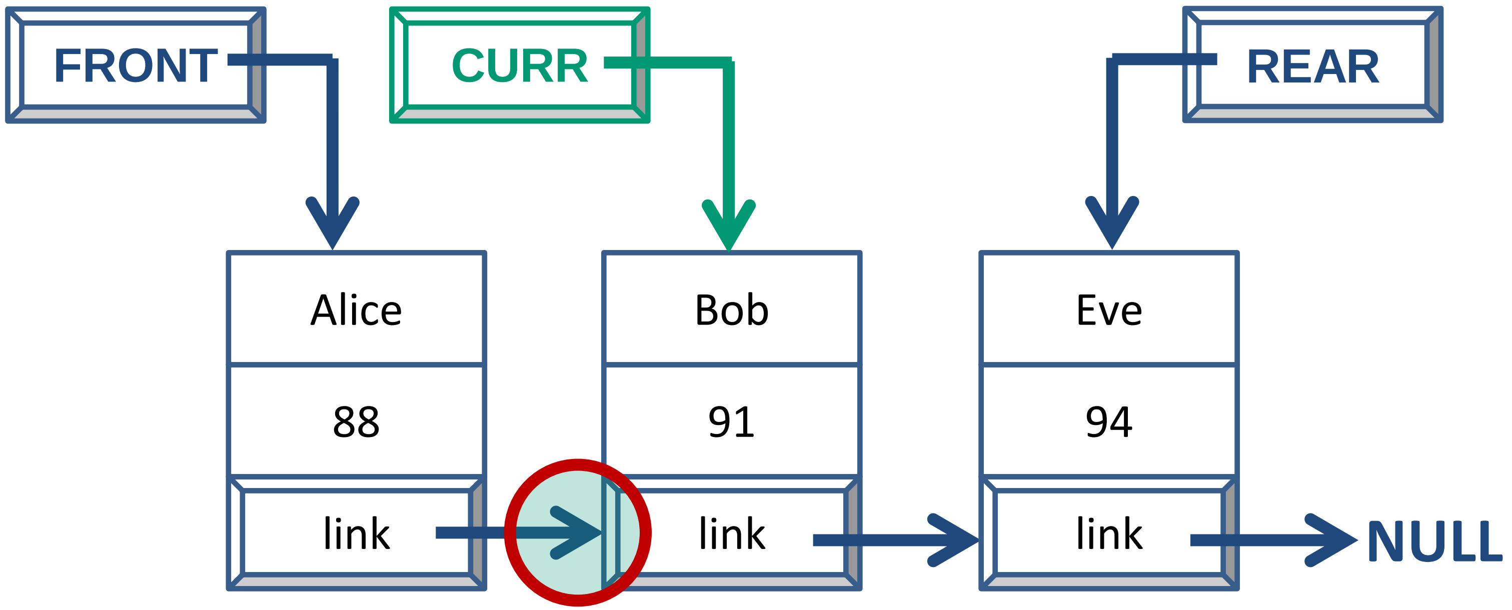
```
    // print information (Alice)
```

Demonstration of Traversal



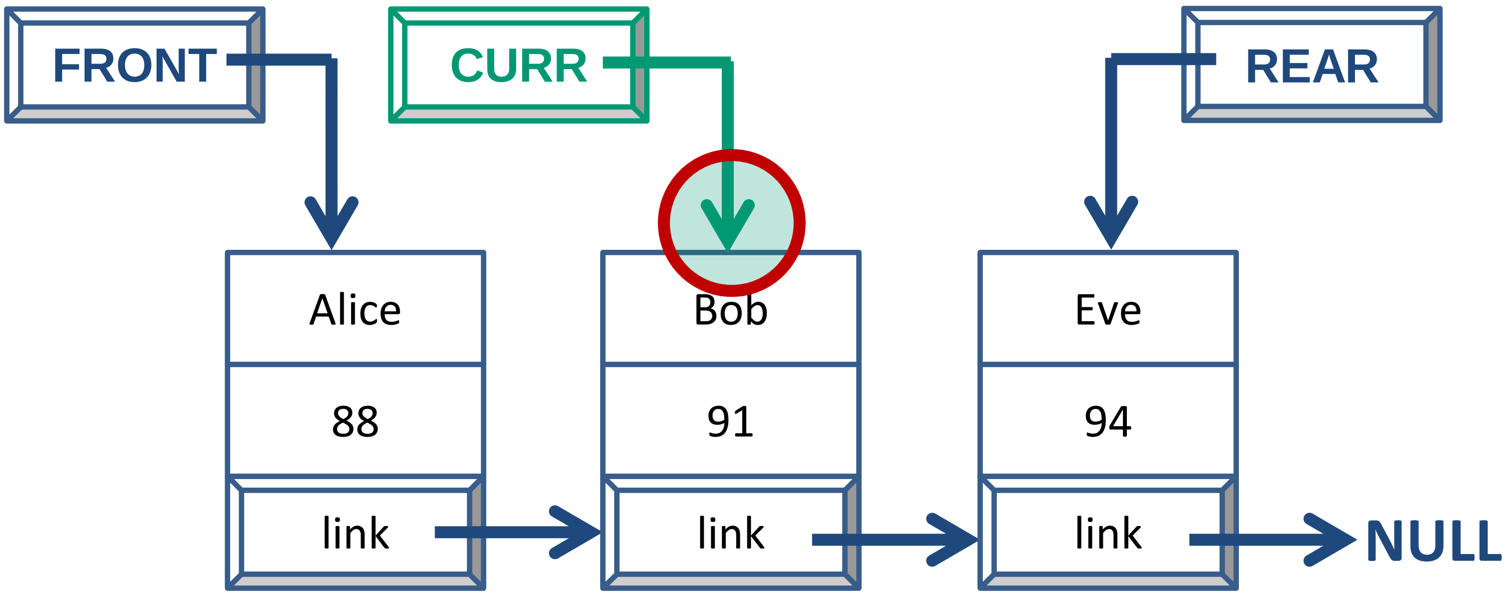

```
for (CURR = FRONT; CURR != NULL; CURR = CURR->link  {
```

Demonstration of Traversal




```
for (CURR = FRONT; CURR != NULL; CURR = CURR->link {
```

Demonstration of Traversal

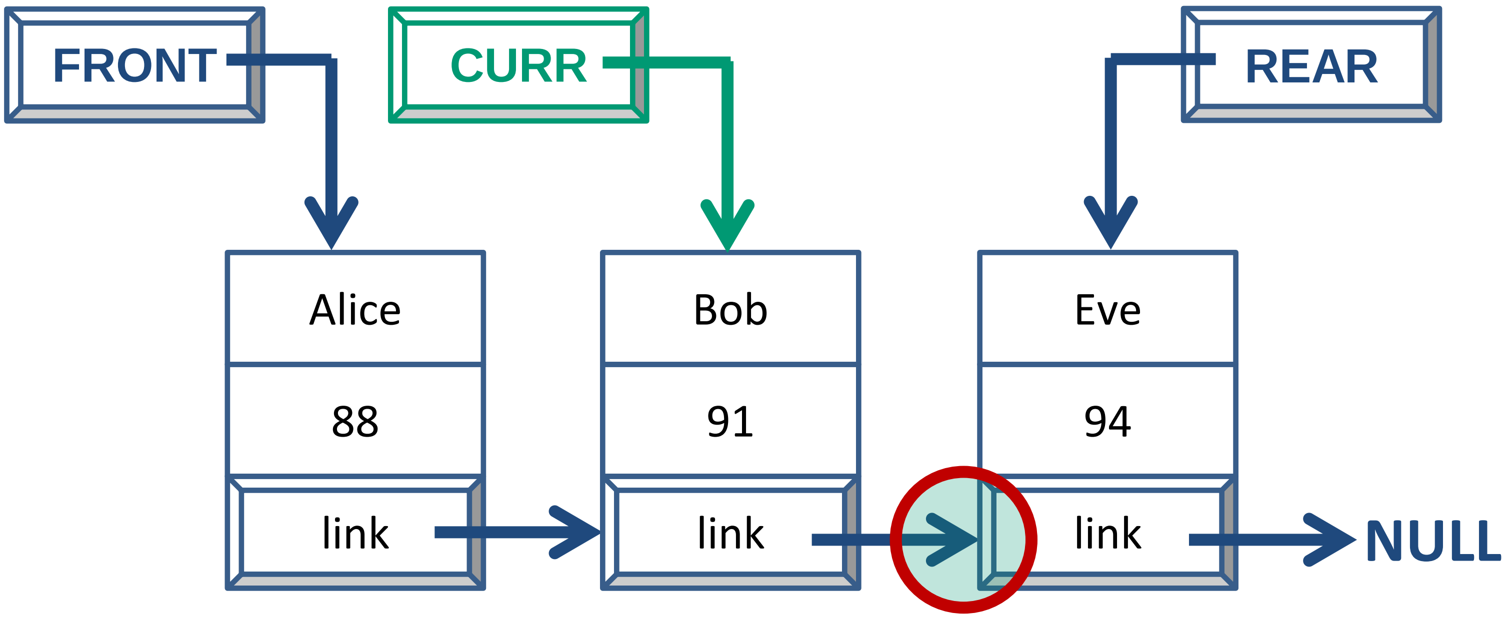



```
for (CURR = FRONT; CURR != NULL; CURR = CURR->link) {
```

✓

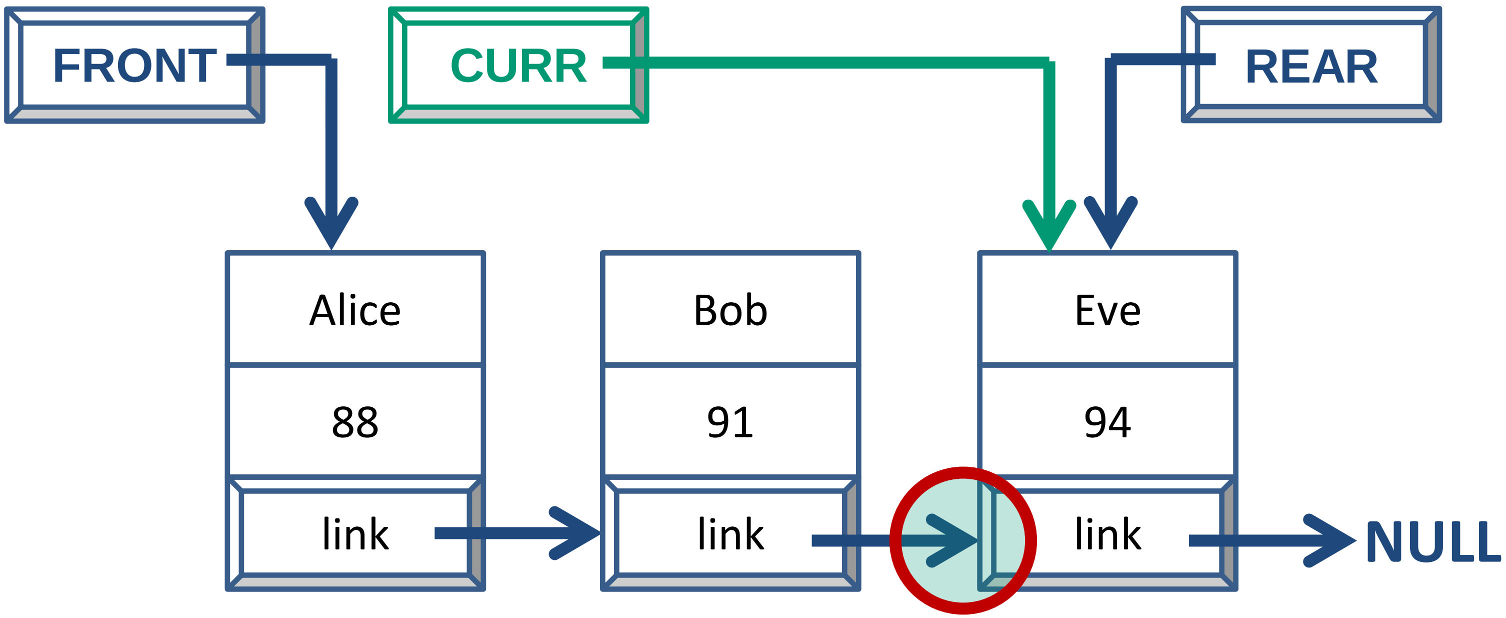
```
    // print information (Bob)
```

Demonstration of Traversal



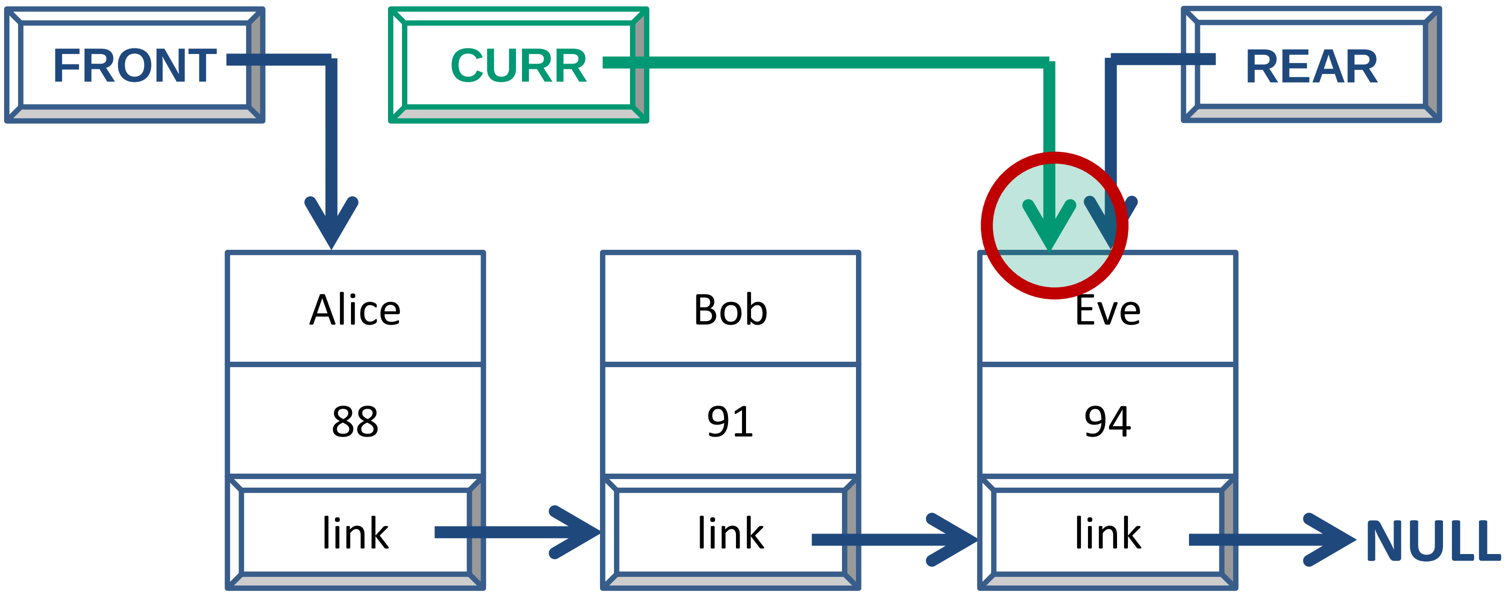

```
for (CURR = FRONT; CURR != NULL; CURR = CURR->link  {
```

Demonstration of Traversal




```
for (CURR = FRONT; CURR != NULL; CURR = CURR->link) {
```

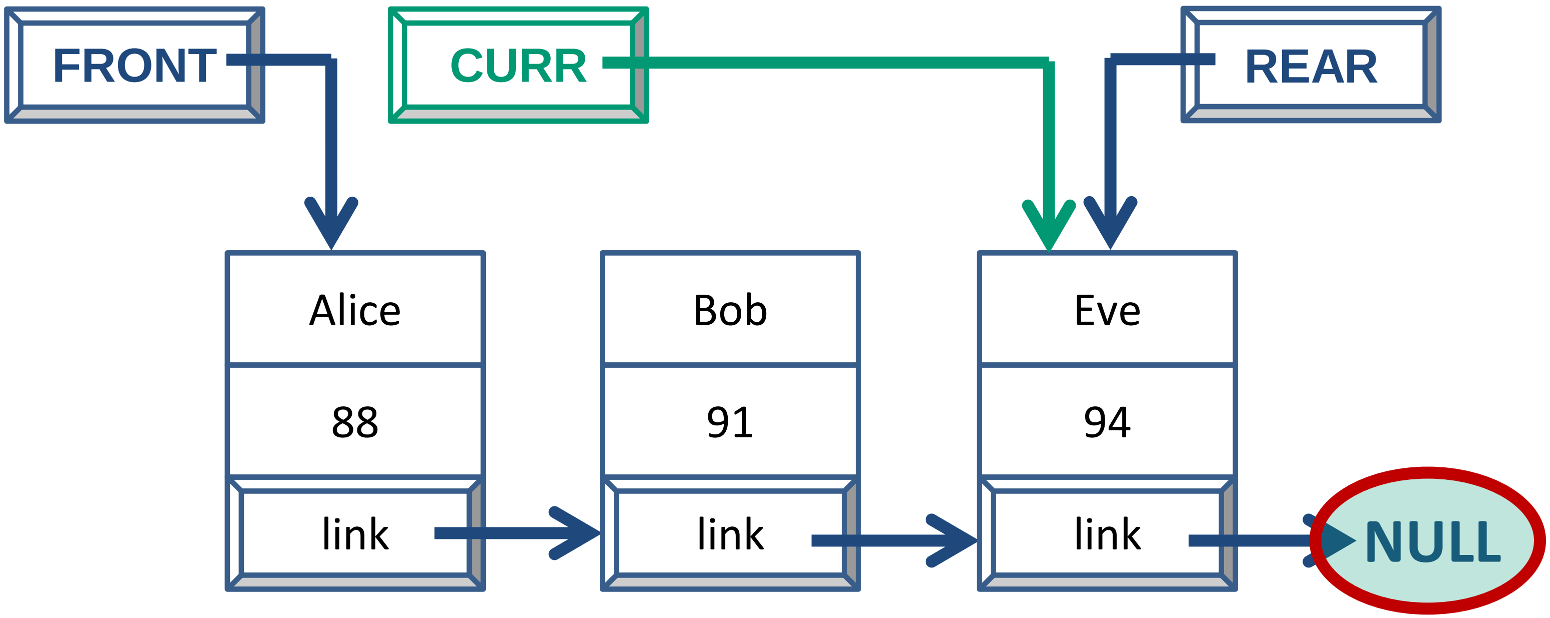
Demonstration of Traversal




```
for (CURR = FRONT; CURR != NULL; CURR = CURR->link) {
```

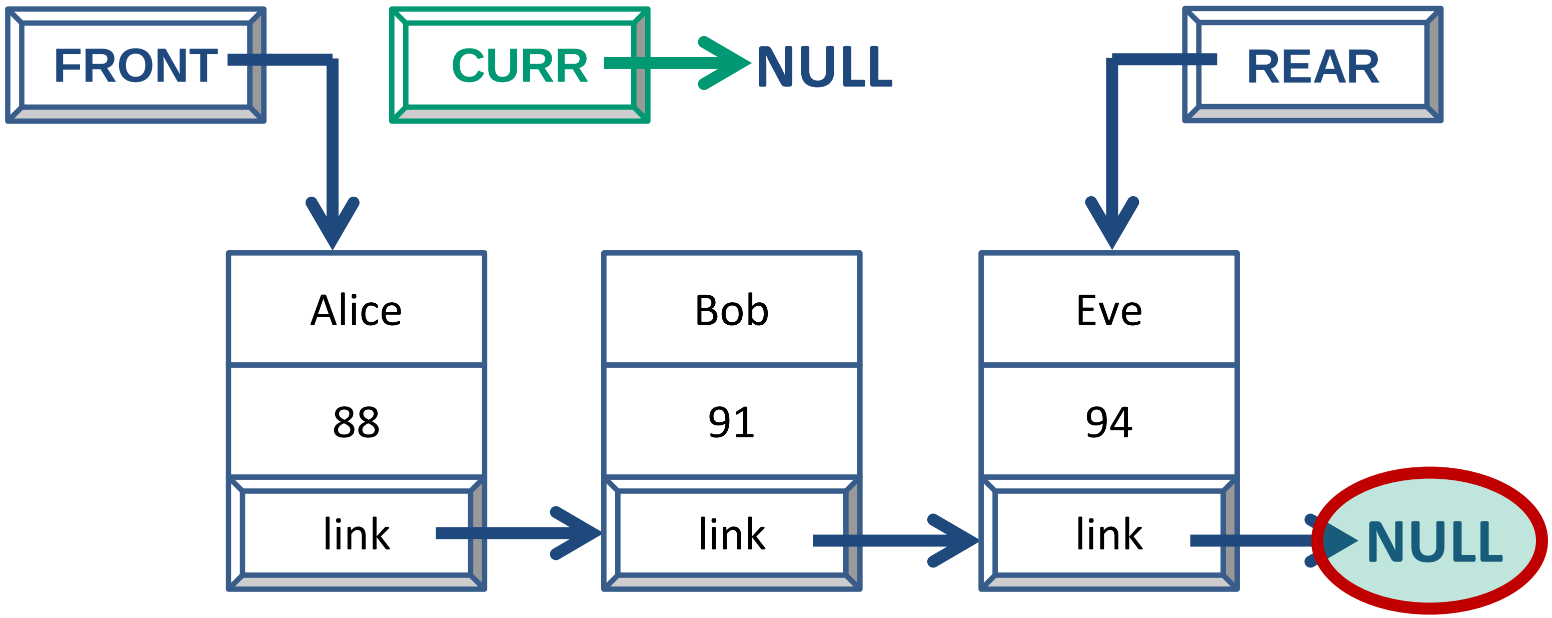
```
    // print information (Eve)
```

Demonstration of Traversal



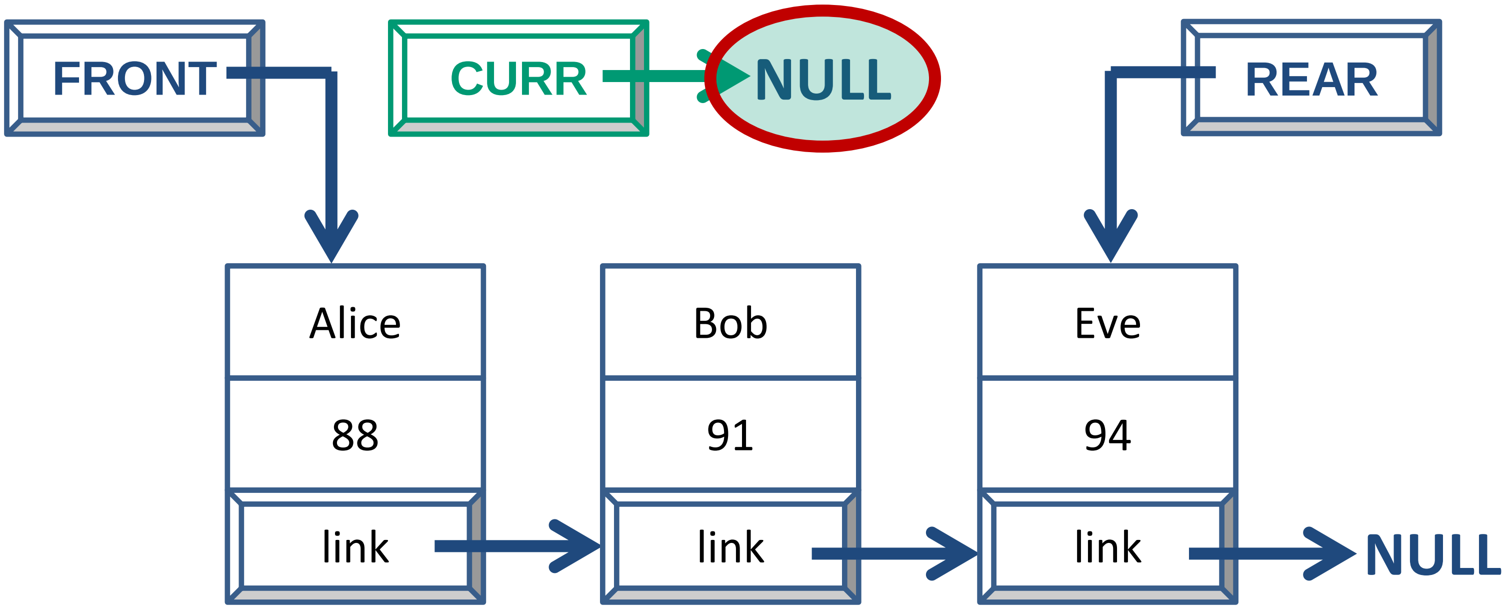

```
for (CURR = FRONT; CURR != NULL; CURR = CURR->link  {
```

Demonstration of Traversal




```
for (CURR = FRONT; CURR != NULL; CURR = CURR->link  {
```

Demonstration of Traversal




```
for (CURR = FRONT; CURR != NULL; CURR = CURR->link) {
```

```
}  // exit the loop
```

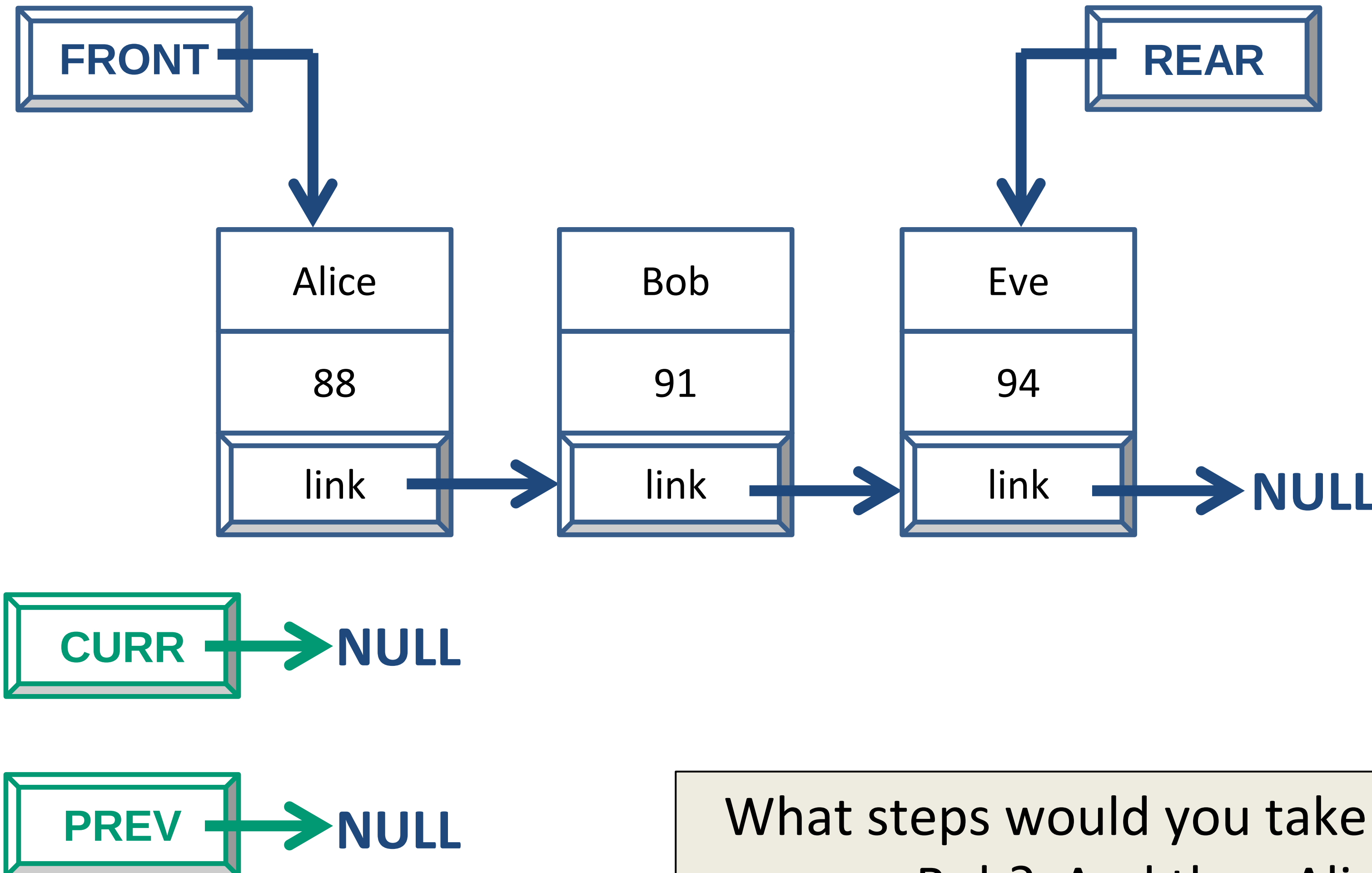
Deletion from a Linked List

Special Cases

- Deletion has many special cases, including…
  - Deleting the only node
  - Deleting the last node
  - Deleting the first node
  - Deleting any “middle” node

- We will need to use **`CURR`** and **`PREV`** here
  - Why? What will we use **`PREV`** for?

Exercise: Deleting from a Linked List



What steps would you take to remove Bob? And then Alice?

Traversing for Deletion

- We will use **`CURR`** and **`PREV`** to keep track of where we are in the Linked List

- We will search for the target
  - If found, we will delete the node
    - And update the **`link`** of the node before it
  - If not found, we will return **`False`**
    - If we reach the end of the list (**`NULL`**)

Looking at the Code

```
boolean Linked_List::remove(String target) {
    CURR = PREV = NULL;

    for (CURR = FRONT; CURR != NULL; CURR = CURR->link) {
        if (CURR->name == target) {
            // WE MADE A MATCH!
            // here's where the deletion will happen
            return true;
        } else {
            PREV = CURR;
            // the for loop will move CURR to next node
        }
    }
    return false;
}
```

Deletion Code

- What are the three possible locations?
  1. First node in the list
  2. Last node in the list
  3. Node in the middle of the list

```
if (CURR->name == target) {
    // WE MADE A MATCH!

    if (CURR == FRONT) {}            // first node
    else if (CURR == REAR ) {}       // last node
    else {}                          // middle of the list

}
```

Deletion Code

- Inside each conditional, you must first fix the links around the target node
- Then delete the target node (CURR)

```
if (CURR->name == target) {
    // WE MADE A MATCH!

    if (CURR == FRONT) {}          // first node
    else if (CURR == REAR ) {}     // last node
    else {}                        // middle of the list
    delete CURR;
}
```

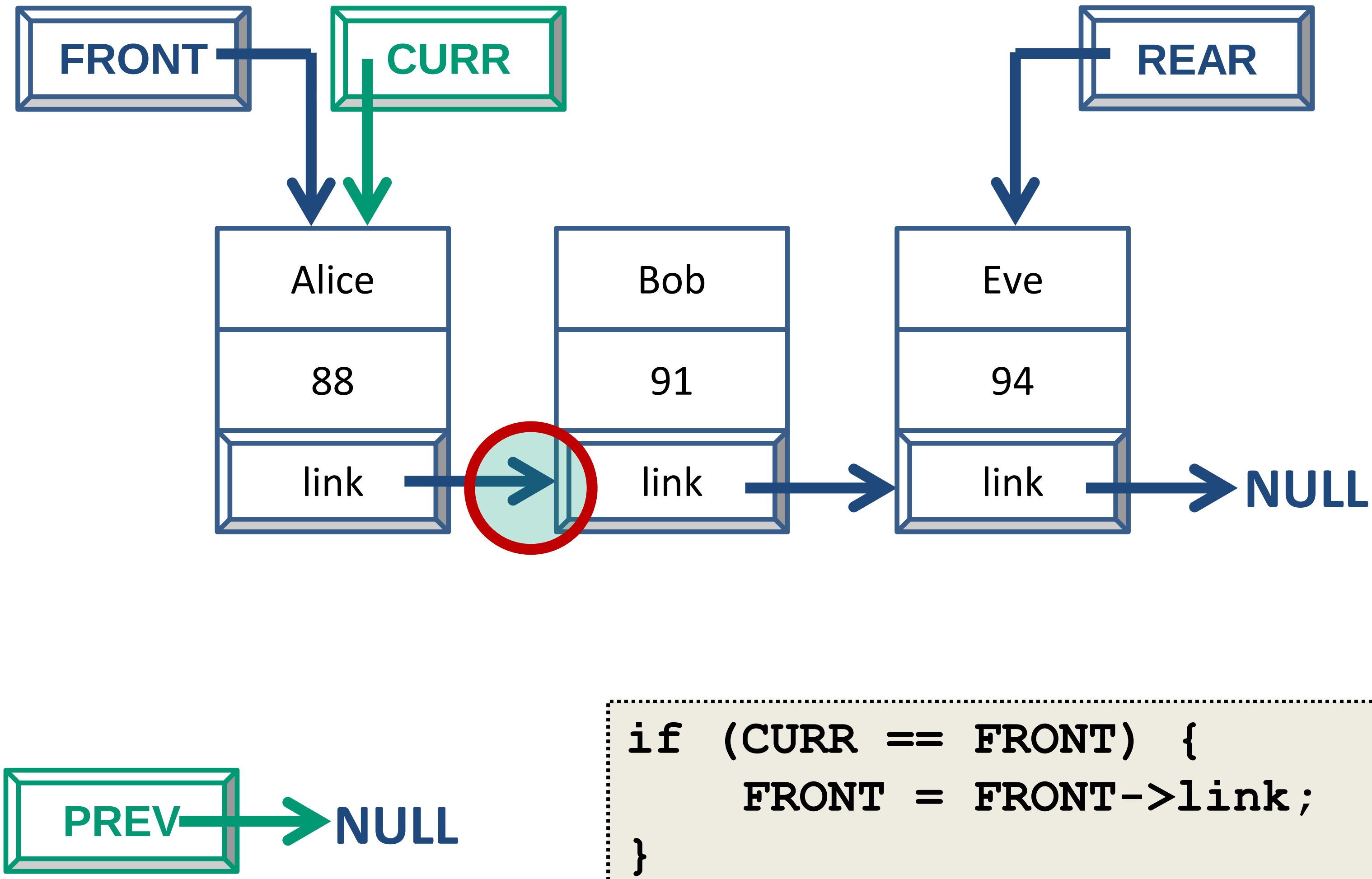
Order of Deletion Operations

- IMPORTANT:
- Deleting a node is the **last** thing that happens

- Before deletion, you must update **all** of the other nodes that currently point to it

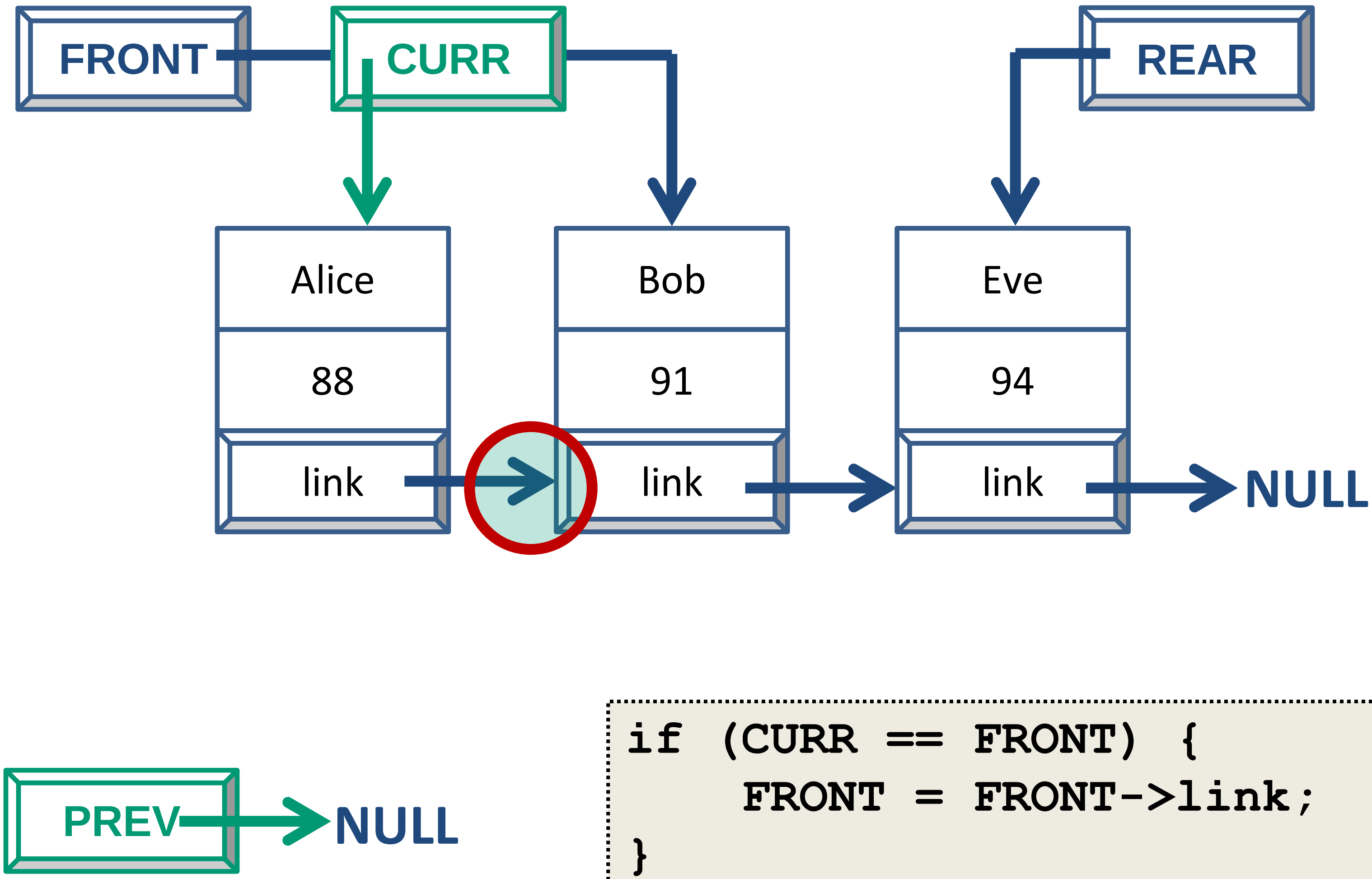
Deletion Case 1:
First Node in Linked List

Deletion Case 1: First Node



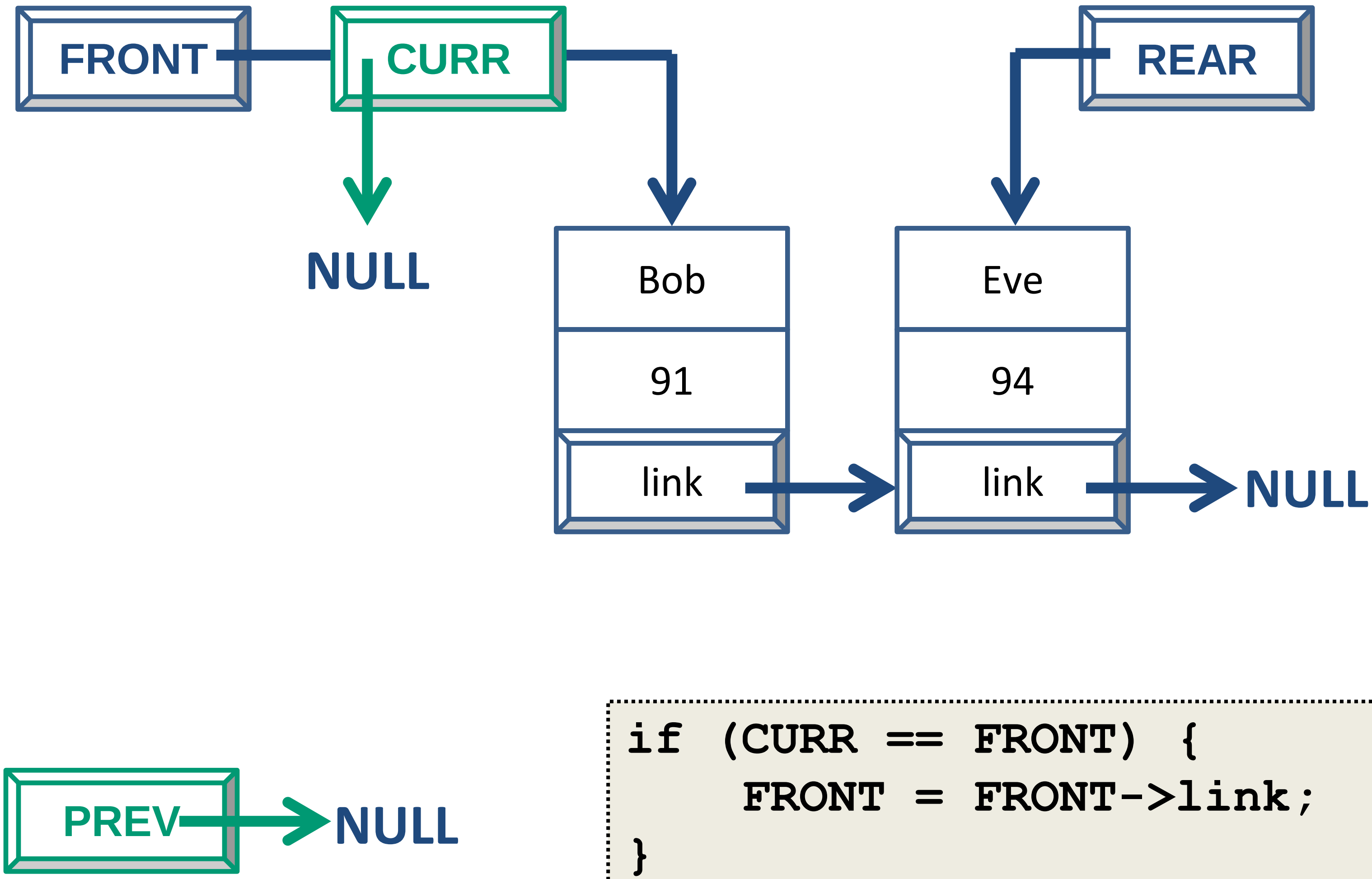

```
if (CURR == FRONT) {
     FRONT = FRONT->link;
}
```

Deletion Case 1: First Node




```
if (CURR == FRONT) {
     FRONT = FRONT->link;
}
delete CURR;
```

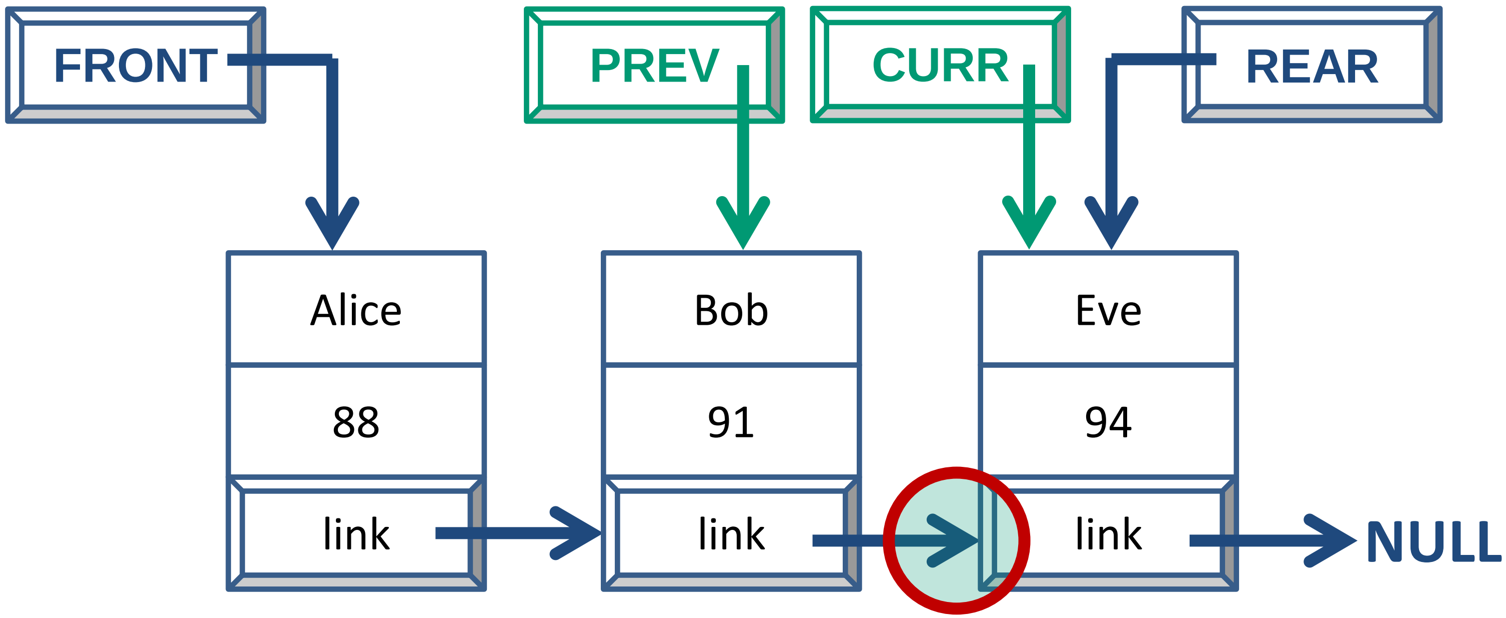
Deletion Case 1: First Node




```
if (CURR == FRONT) {
    FRONT = FRONT->link;
}
delete CURR;
```

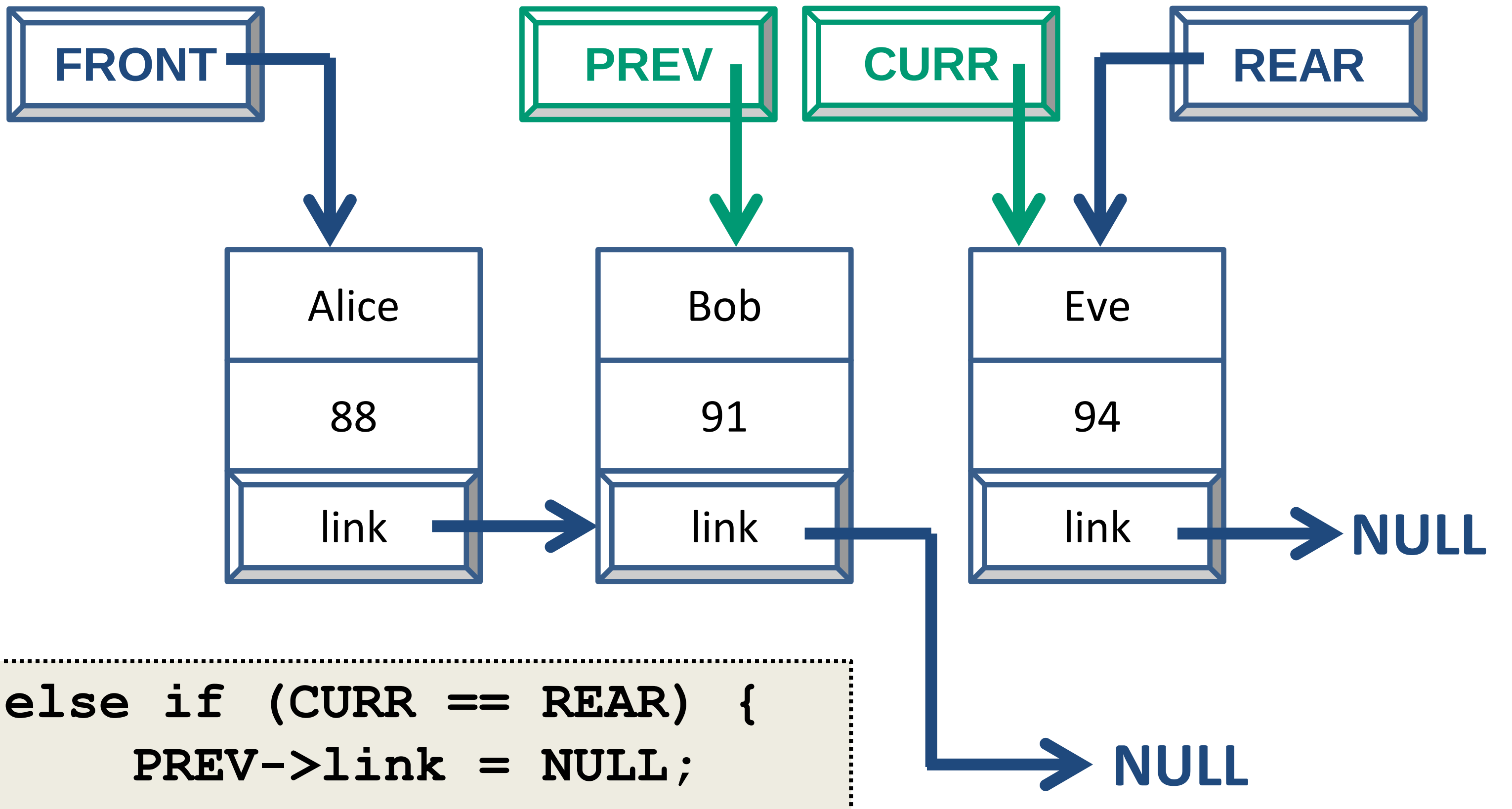
Deletion Case 2:
Last Node in Linked List

Deletion Case 2: Last Node



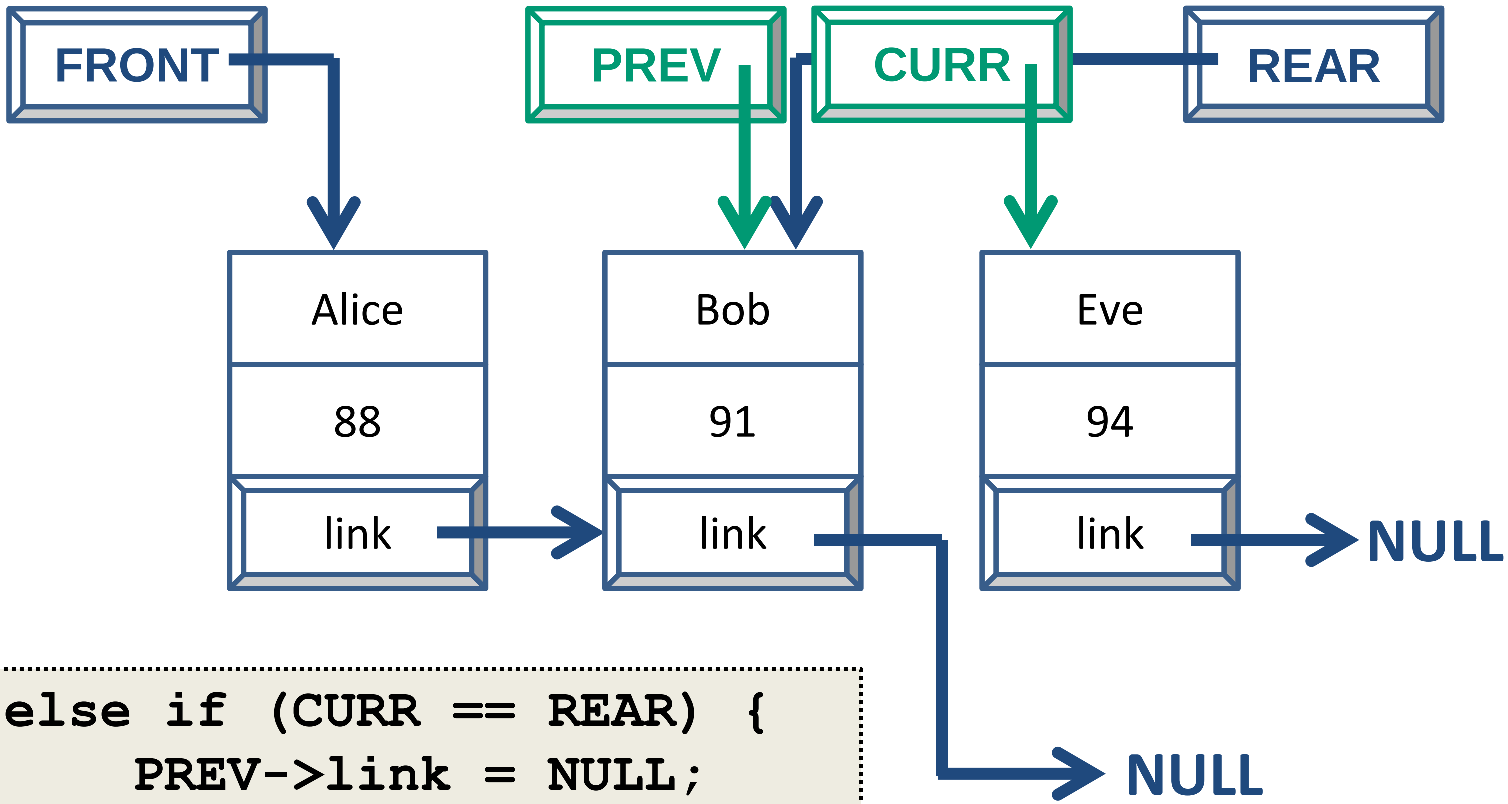

```
else if (CURR == REAR) {
    PREV->link = NULL;

}
```

Deletion Case 2: Last Node



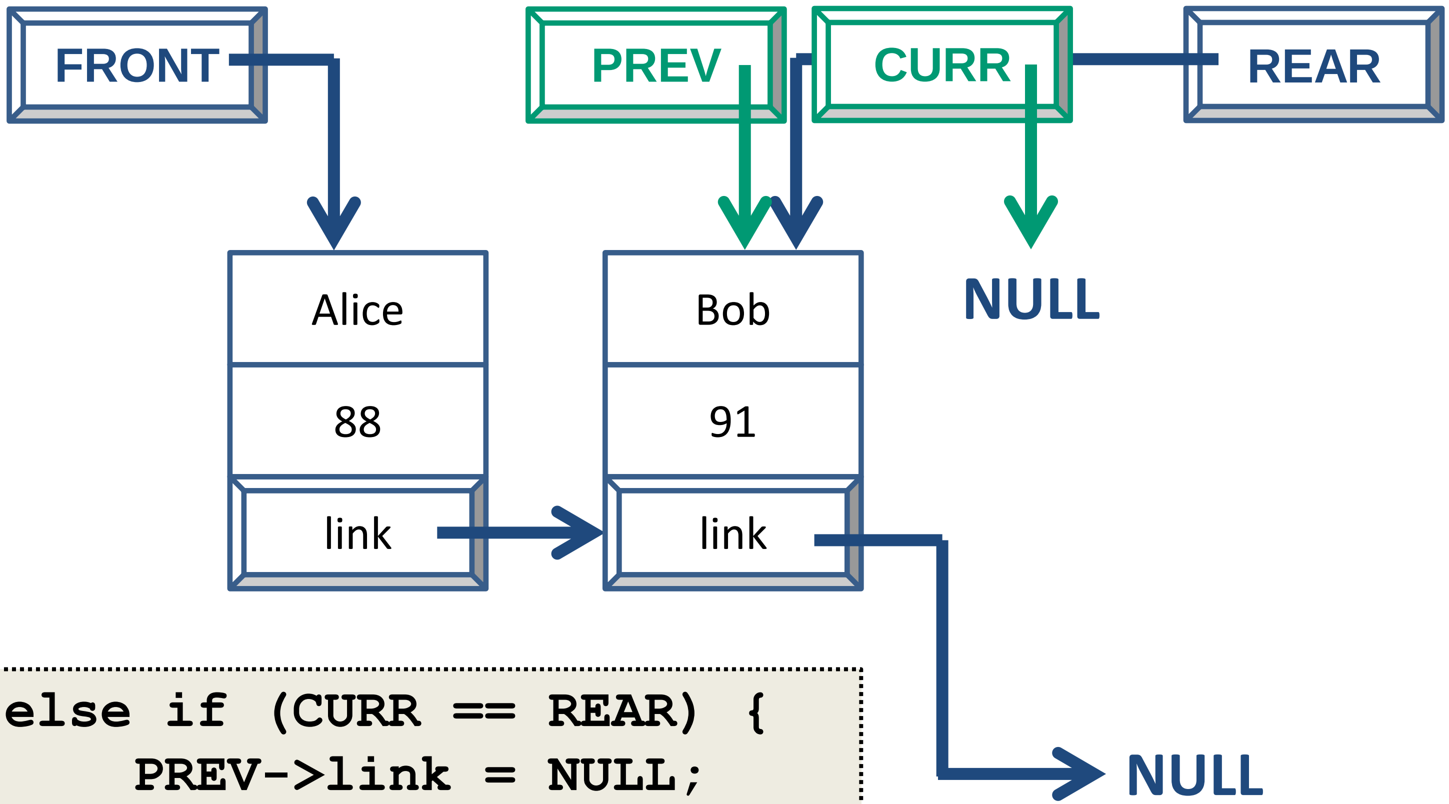

```
else if (CURR == REAR) {
    PREV->link = NULL;
    REAR = PREV;
}
```

Deletion Case 2: Last Node




```
else if (CURR == REAR) {
     PREV->link = NULL;
     REAR = PREV;
}
delete CURR;
```

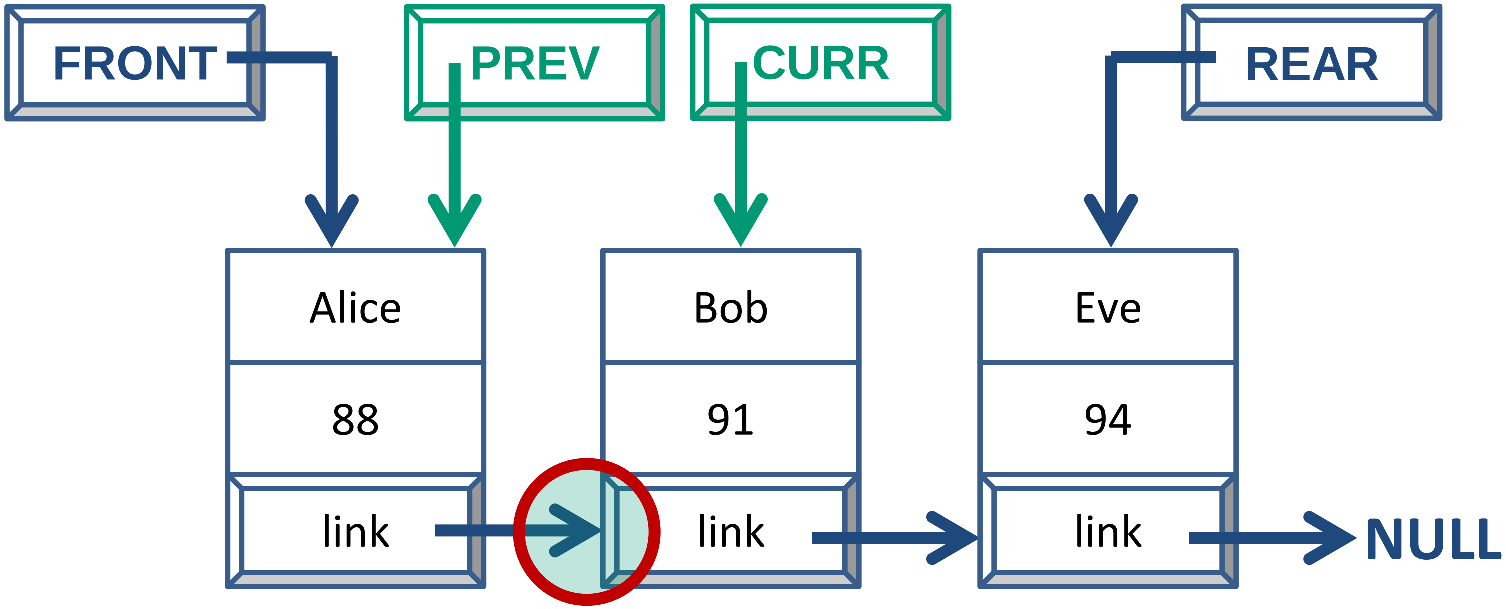
Deletion Case 2: Last Node




```
else if (CURR == REAR) {
     PREV->link = NULL;
     REAR = PREV;
}
delete CURR;
```

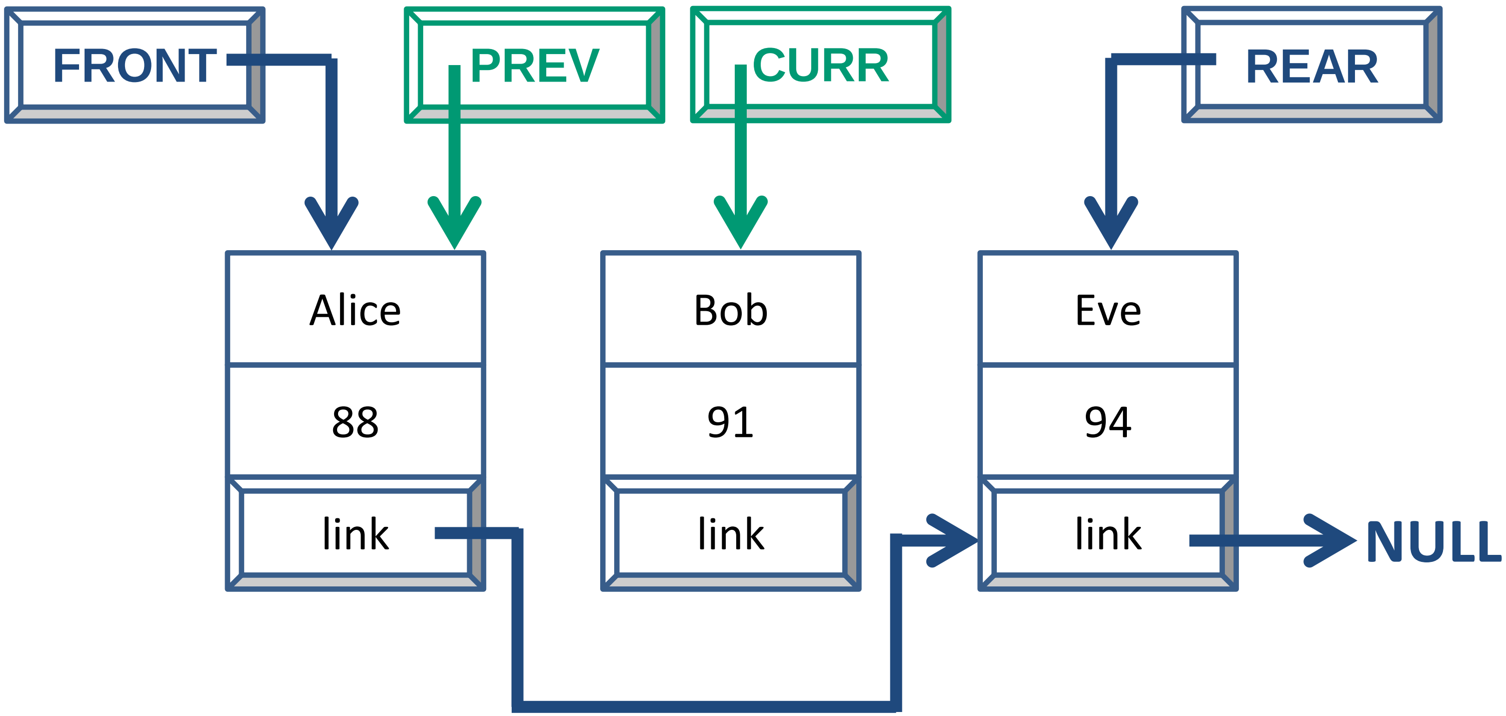
Deletion Case 3:
Node in Middle of Linked List

Deletion Case 3: Middle Node



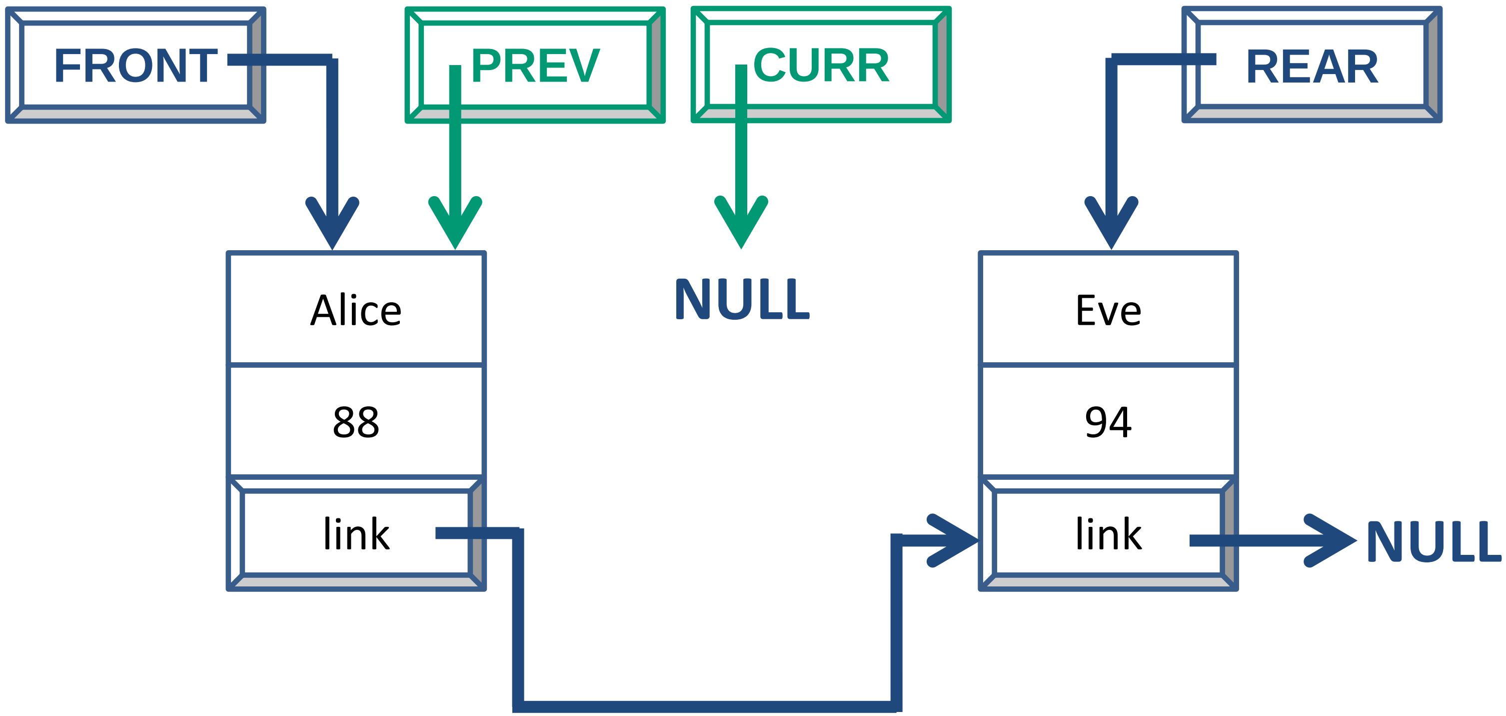

```
else {    //middle node
    PREV->link = CURR->link;
}
```

Deletion Case 3: Middle Node




```
else {    //middle node
    PREV->link = CURR->link;
}
delete CURR;
```

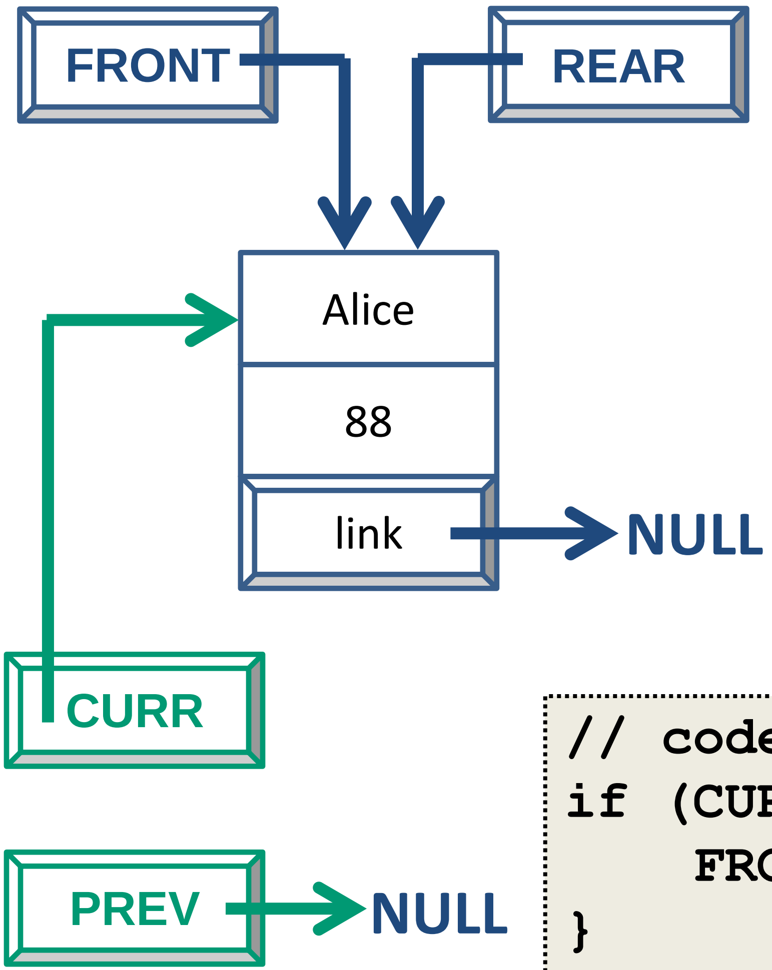
Deletion Case 3: Middle Node




```
else {    //middle node
    PREV->link = CURR->link;
}
delete CURR;
```

Special Deletion Case:
Only Node in Linked List

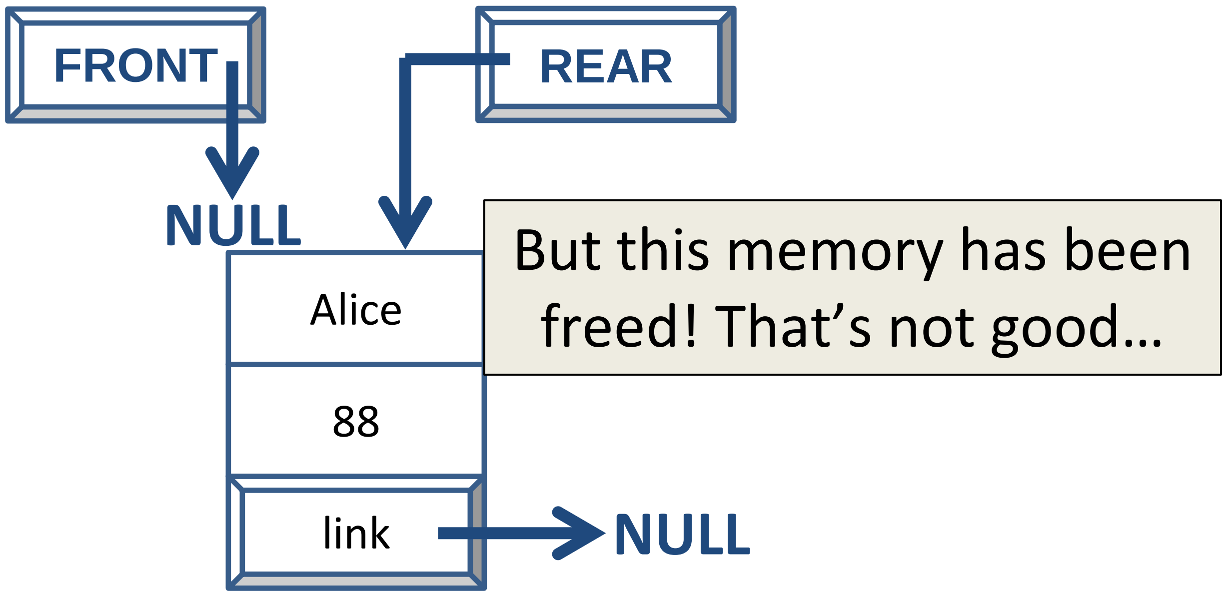
Special Deletion Case: Only Node

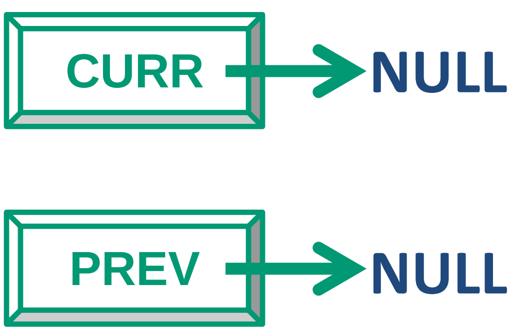


What happens to **REAR** with this code? What does it point to?

```
// code that currently handles this
if (CURR == FRONT) {
     FRONT = FRONT->link;
}
delete CURR;
```

Special Deletion Case: Only Node






```
// code that currently handles this
if (CURR == FRONT) {
    FRONT = FRONT->link;
}
delete CURR;
```

Special Deletion Case: Only Node

- If we are removing the only node from a Linked List, we need to set both **FRONT** and **REAR** to point to **NULL**

```
// new case for last node
if (CURR == FRONT && CURR == REAR) {
    FRONT = FRONT->link;
    REAR  = REAR->link;
    // or FRONT = NULL;
    //    REAR  = NULL;
}
delete CURR;
```