People's Democratic Republic of Algeria
Ministry of higher education and scientific research
University of Mohamed Boudiaf - M'sila

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2nd Year License (2L)

Data Structures and Algorithms 3 (DSA3)

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- In case of problems or difficulties, please contact me or your TD / TP teacher.
- We are at your disposal to help you

CHAPTER 3

Linked Lists, Stacks and Queues

Plan

I. Introduction

II. Pointers

III. Linked-Lists

IV. Stacks

V. Queues

I. Introduction

- If your program needs to store a few items - numbers, payroll records, or job descriptions, for example - the simplest and most efficient approach is **to place them in a list.**
- The **array is one of the most popular representations**, offering a convenient way of storing collections of items, and whose loops and iterations allow us to process these items sequentially.

I. Introduction

- However, **arrays are not always the most efficient way to store collections of items**.
- In this chapter, we shall see that **lists may be a better way to store collections of items**, and how recursion may be used to process them.
- This chapter describes list representations in general, as well as **two important linked list structures: the stack and the queue.**

II. Pointers

- Pointers play a fundamental role in many algorithms and programming languages, particularly in C (C++).
- In algorithms, pointers **enable data to be accessed and manipulated efficiently** by **referring to their memory address rather than to direct values**.
- A pointer is a **variable that contains the memory address of another variable.**

II. Pointers

- Therefore, when we manipulate a pointer in C (C++), we have **direct control over the computer's memory**.
- This provides considerable flexibility and power in the design of efficient algorithms.
- Using pointers, programmers can **dynamically allocate and free memory,** pass data addresses between functions, and implement complex data structures such as **linked lists and trees**.

II. Pointers

Definition III.1

A **pointer** is a **variable** that **stores the memory address of another variable**. It allows **indirect access** to the value stored at that address. A pointer is defined by its :

- name,
- pointed type and
- memory location reserved for a specific address (Value).

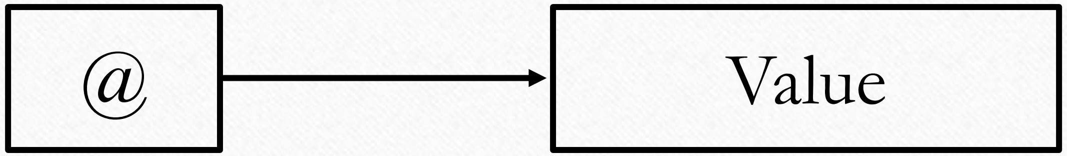
A pointer to a type T is a variable that contains the address of a **variable of type T**.

II. Pointers

Declaring a pointer

- The syntax of pointers is similar to the variable declaration in C, but we use the **(*) dereferencing operator** in the pointer declaration.

datatype *px;



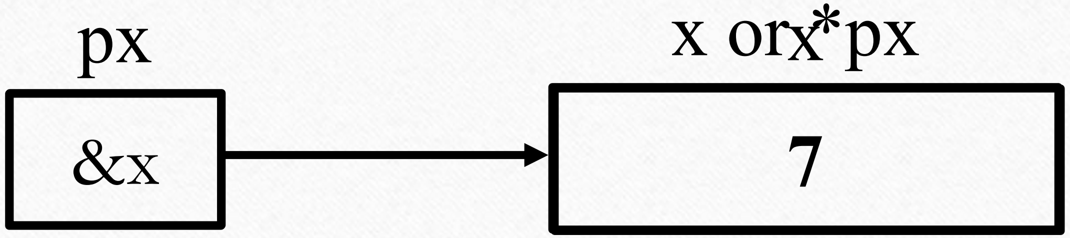
Where :

- **px** is the name of the pointer.
- **datatype** is the type of data it is pointing to.

II. Pointers

Example :

```
#include <stdio.h>
int main(void) {
    int x;
    int *px;      //pointer to int
    x = 7;
    px = &x;
    printf(" x = %d\n", x);
    printf(" px = %p\n", px);
    printf("*px = %d\n", *px);
    return 0;
}
```



x = 7
px = 0x75487A
*px = 7

- If $\boldsymbol{x}$ is an integer: &$\boldsymbol{x}$ is a pointer to $\boldsymbol{x}$ (memory address of $\boldsymbol{x}$)
- If $\boldsymbol{px}$ is a pointer to an integer: $*\,\boldsymbol{px}$ is the integer

III. Linked-Lists

- The linked list is a **linear data structure**, in which data elements are **not stored in contiguous memory locations,** as is the case with arrays.
- The elements of the linked list are **connected by pointers**, which serve as **a link to the next data** element.
- Each element of the linked list is a **separate object called a node**.

III. Linked-Lists

- Each node contains **data and points to the next node**, creating a sequence.
- Linked list is very common data structure that is used to create tree, graph and other abstract data types.

III. Linked-Lists

Properties of Linked List

- A linked list is a **linear collection of data-elements**, called **"nodes".** The linear order is maintained by pointers.
- The linked list starts with a **HEAD** which denotes the starting point or the memory location of the first node, the end of the list is called the **TAIL.**
- The Linked-list ends with the last node pointing to **NULL** value.

III. Linked-Lists

Properties of Linked List

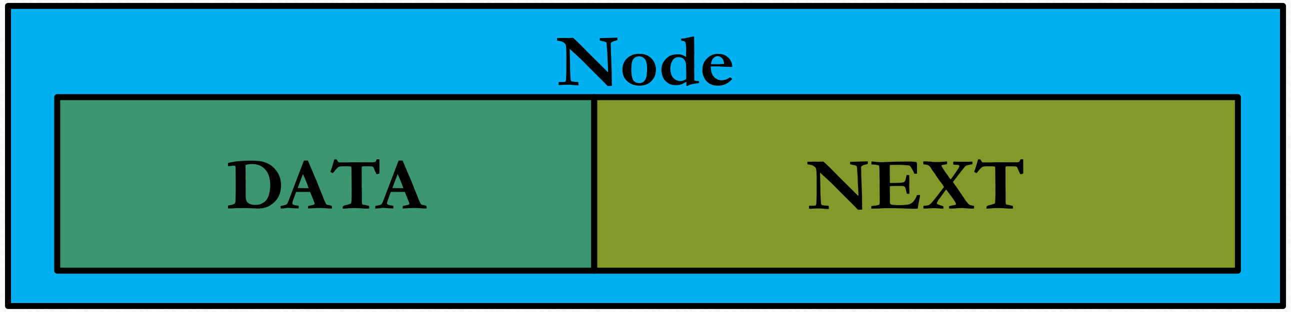
- It can be visualized as a **chain of nodes** where each node contains the location of the next node.
- Unlike arrays, linked list elements are **not stored at contiguous memory locations**.
- Linked lists address some of the limitations of arrays that have a fixed size because Linked lists link dynamically.
- Linked List does not waste memory space.

III. Linked-Lists

Representation of Linked List

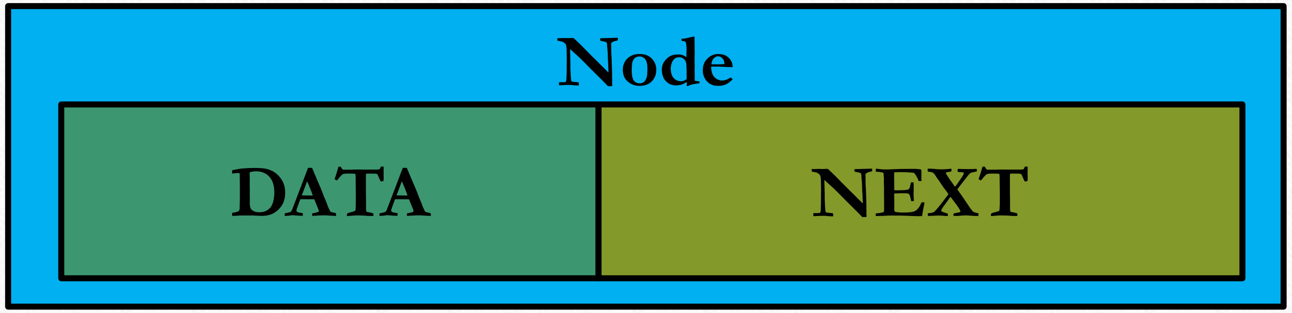
A linked list is a chain of nodes, and each node has the following parts:

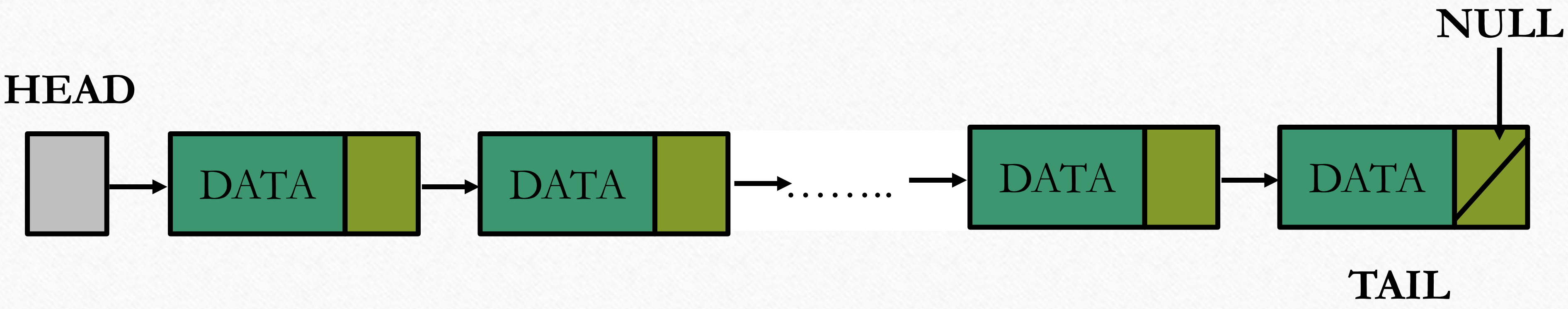
- **Data** : Stores the information
- **Next** : Stores the address to next node



III. Linked-Lists

Representation of Linked List





III. Linked-Lists

Declaration of Linked List

Declaration of the type of elements or nodes

- We first define a node with two components:
  1) a place for storing data, and
  2) a pointer to the next node in the chain.
- We define a linked list in a struct using the below code:

III. Linked-Lists

Declaration of Linked List

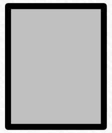
```
struct Node {
 int data;
 struct Node* next;
};
typedef Node* LIST;
```

III. Linked-Lists

Declaration of Linked List

- Now, we might have a variable of type **LIST** called **List**:

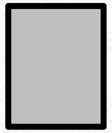
List



```
LIST List;
```

- Now, we might have a variable of type **Node*** called **newNode**:

newNode



```
Node* newNode  =new Node;
```

III. Linked-Lists

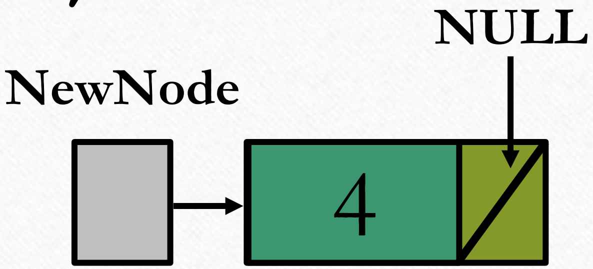
Creating a Node in a Linked List

- The creation of a linked list starts with **creating a node.**
- Sufficient memory must be allocated when a node is created.
- Information is stored in memory using the **malloc()** or **new()** functions.

III. Linked-Lists

Creating a Node in a Linked List

```
struct Node * newNode;
newNode = new(Node);
newNode -> data = 4;
newNode -> next = NULL;
```



III. Linked-Lists

Creating a Node in a Linked List

- The above definition is used to create every node in the list.
- The **data** field stores the element and the **next** is a pointer to store the address of the next node.
- We can only move in the direction of the link. That is, we can move from a node to the node next to it but we cannot go back to the previous node.

III. Linked-Lists

Implementing the Basic linked list Operations

A. Constructor

- The constructor simply initializes the **head (List)** pointer to be equal to **NULL** to indicate an initially **empty list** (it does not refer to any node).

```
LIST List = NULL;
```

```
//We can use nullptr instead of NULL
```

B. Empty

- We can then perform the second list operation, determining whether a list is empty, simply by checking whether the **head (List)** is **NULL**:

```
List = NULL;
```

```
//We can use nullptr instead of NULL
```

III. Linked-Lists

Implementing the Basic linked list Operations

C. Traverse

- The third basic list operation is a **traversal** of the list.
- Traversing a linked list is very simple, and means **going through** the linked list by following **the links from one node to the next**.

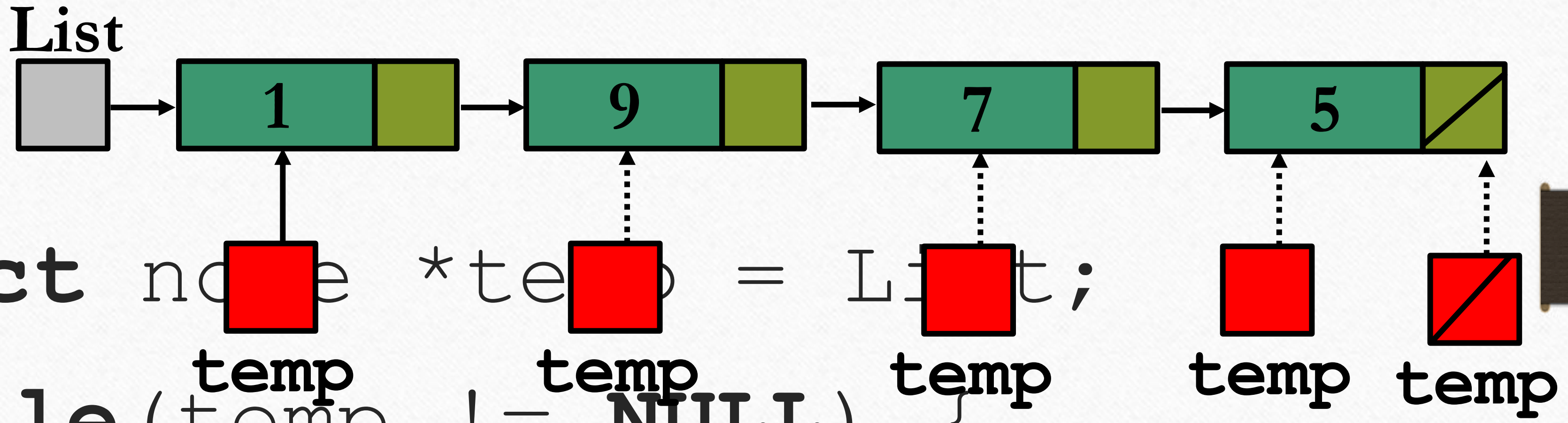
C. Traverse

- To traverse a linked list, we begin by initializing an auxiliary variable **temp** that points to the first node:
- We keep moving the **temp** node to the next one and display its contents.
- When **temp** is **NULL**, we know that we have reached the end of the linked list so we get out of the **while** loop.

III. Linked-Lists

Implementing the Basic linked list Operations

C. Traverse




```
struct node *temp = List;
  while(temp != NULL) {
  temp = temp -> next;
}
```

III. Linked-Lists

Implementing the Basic linked list Operations

D. Displaying a Linked List

- To display the linked list elements, the processing step in this algorithm is simply to output the **data** part of the node.

```
void display(LIST List) {
    cout << "\n\n List elements are : " <<
    endl;
    While( List != NULL) {
    cout << List -> data << "     ";
        List = List -> next;
    }
}
```

E. Insert a Node in a Linked List

- You can add elements to either the beginning, middle or end of the linked list.
- There can be three cases that will occur when we are inserting a node in a linked list.
    - **Insertion at the beginning**
    - **Insertion at the end (Append)**
    - **Insertion after a given node**

III. Linked-Lists

Implementing the Basic linked list Operations

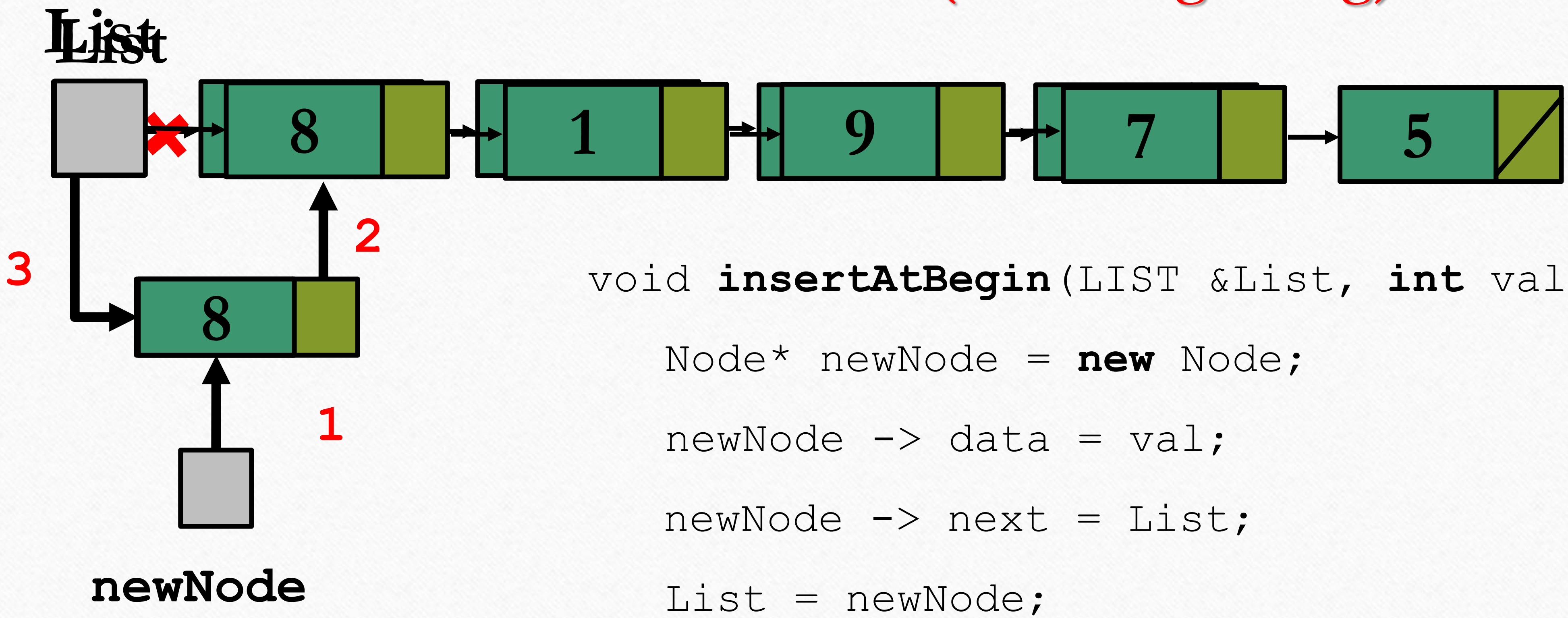
E. Insert a Node in a Linked List (at the beginning)

- Since, there is **no need to find the end of the list**.
- If the list is empty, we make the new node as the **head** of the list.
- Otherwise, we have **to connect the new node to the current head** of the list and make the new node, the head of the list.

III. Linked-Lists

Implementing the Basic linked list Operations

E. Insert a Node in a Linked List (at the beginning)




```
void insertAtBegin(LIST &List, int val){
    Node* newNode = new Node;
    newNode -> data = val;
    newNode -> next = List;
    List = newNode;
}
```

III. Linked-Lists

Implementing the Basic linked list Operations

E. Insert a Node in a Linked List (at the end)

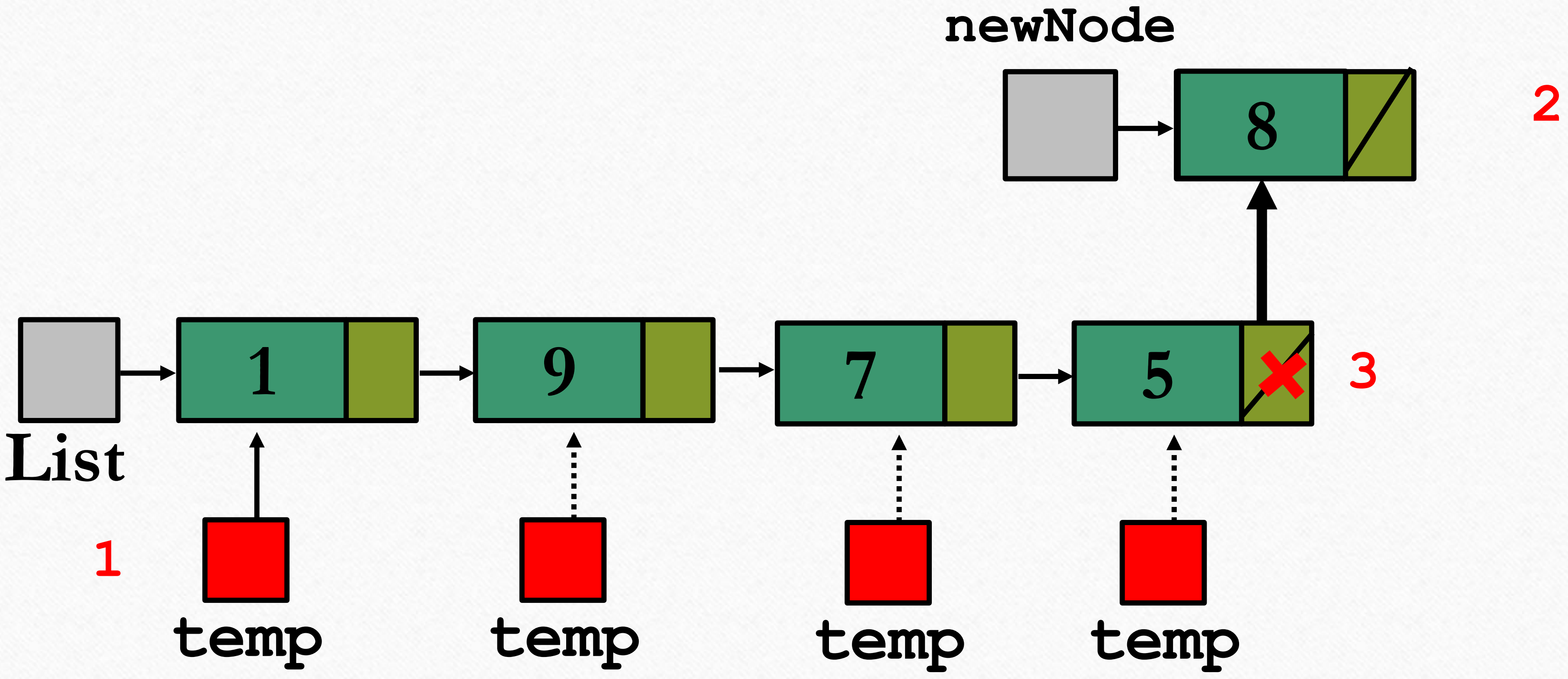
- We will **traverse** the list **until we find the last node.**
- Then we **insert the new node to the end** of the list. Note that we have to consider special cases such as list being empty.
- In case of a list being empty, we will return the updated head of the linked list because in this case, the inserted node is the first as well as the last node of the linked list.

III. Linked-Lists

Implementing the Basic linked list Operations

E. Insert a Node in a Linked List (at the end)

E. Insert a Node in a Linked List (at the end)



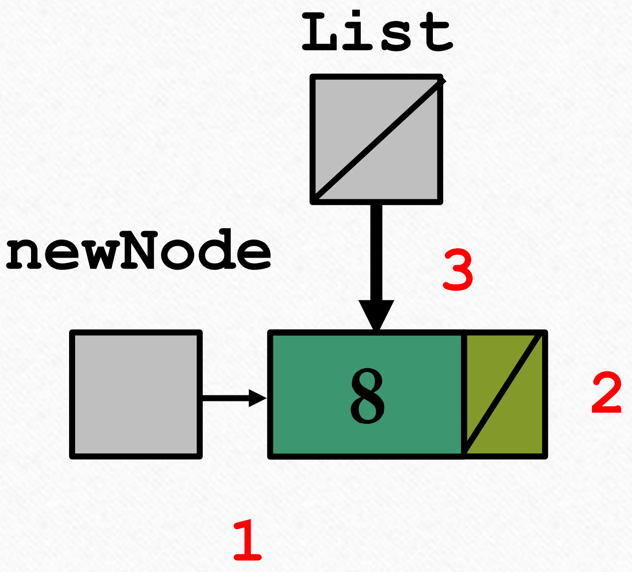
III. Linked-Lists

Implementing the Basic linked list Operations

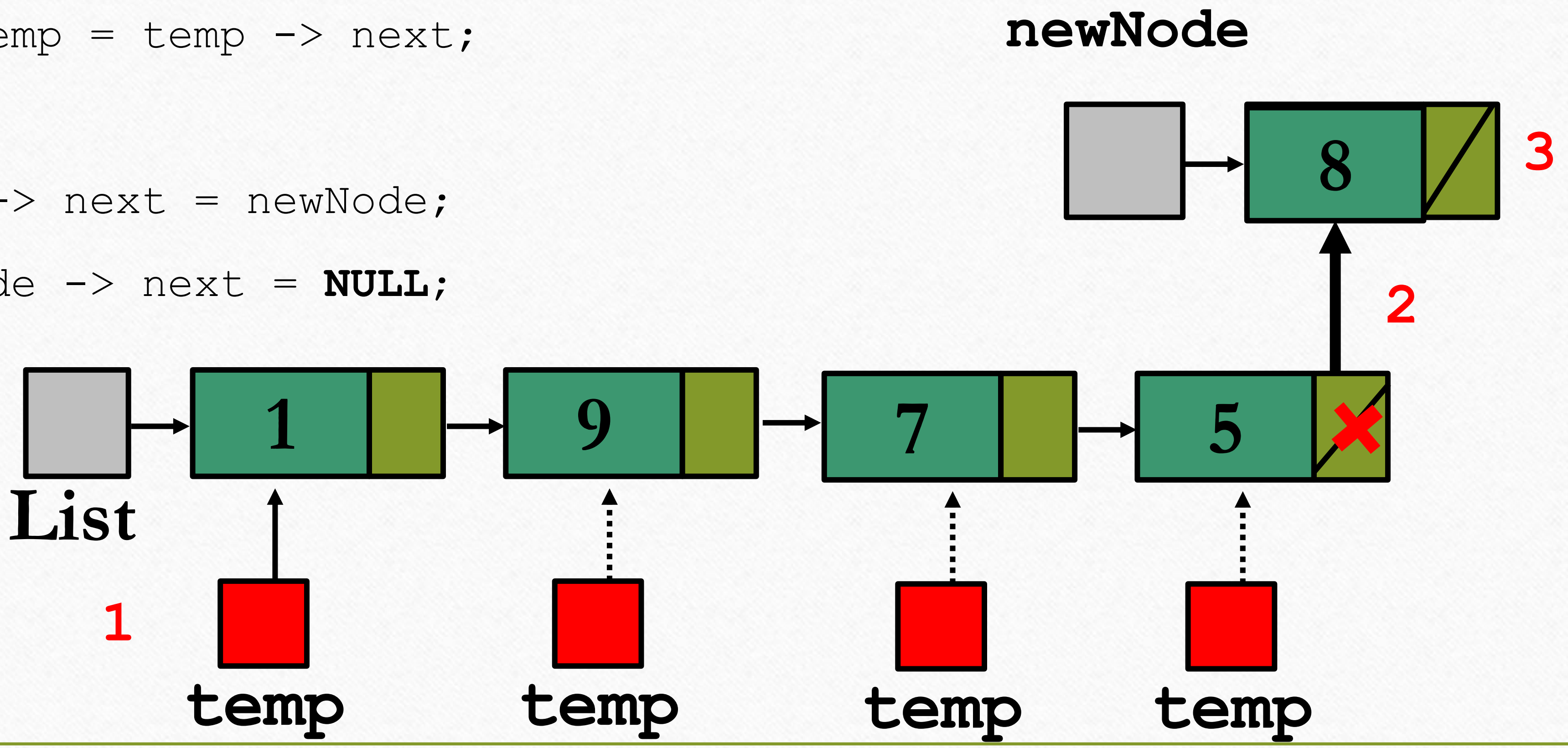
E. Insert a Node in a Linked List (at the end)

```
void insertAtEnd(LIST &List, int val){
    Node* newNode = new (Node);
    newNode -> data = val;
    if( List == NULL ) {
        newNode -> next = List;
        List = newNode;
        return ;
}
LIST temp = List;
while( temp -> next != NULL ){
    temp = temp -> next;
}
temp -> next = newNode;
newNode -> next = NULL;
}
```

```
void insertAtEnd(LIST &List, int val){
    Node* newNode = new (Node);
    newNode -> data = val;
    if( List == NULL ) {
        newNode -> next = List;
        List = newNode;
        return ;
    }
```



```
void insertAtEnd(LIST &List, int val){

//////////////

LIST temp = List;

    while( temp -> next != NULL ){

        temp = temp -> next;

    }

    temp -> next = newNode;

    newNode -> next = NULL;

}
```

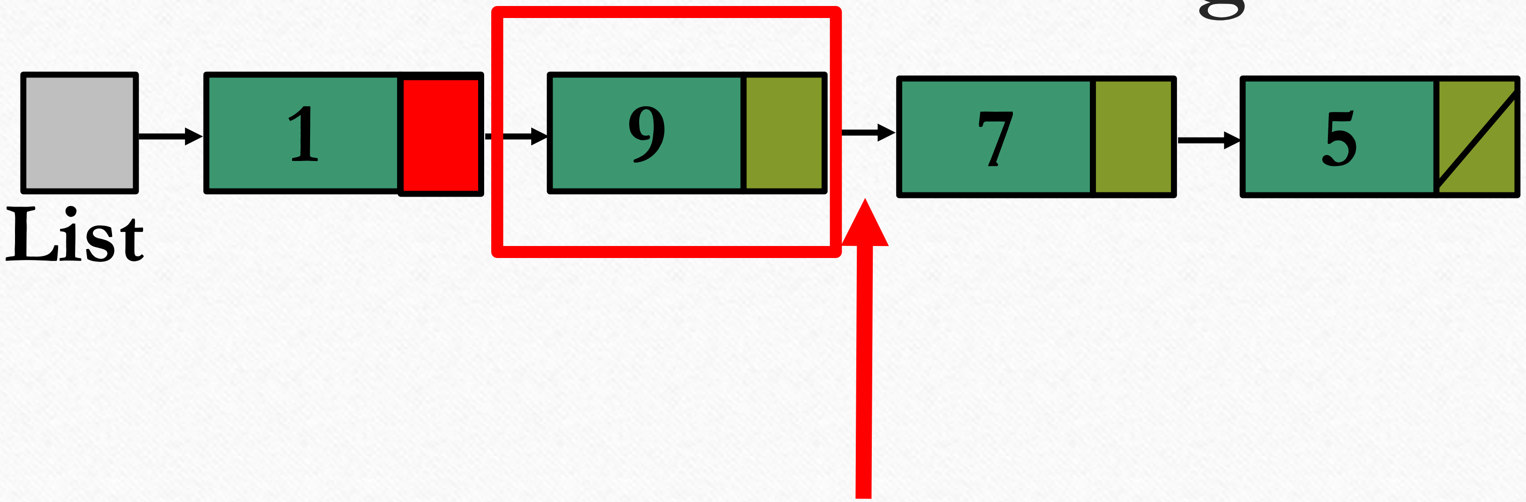


III. Linked-Lists

Implementing the Basic linked list Operations

E. Insert a Node in a Linked List (after a given node)

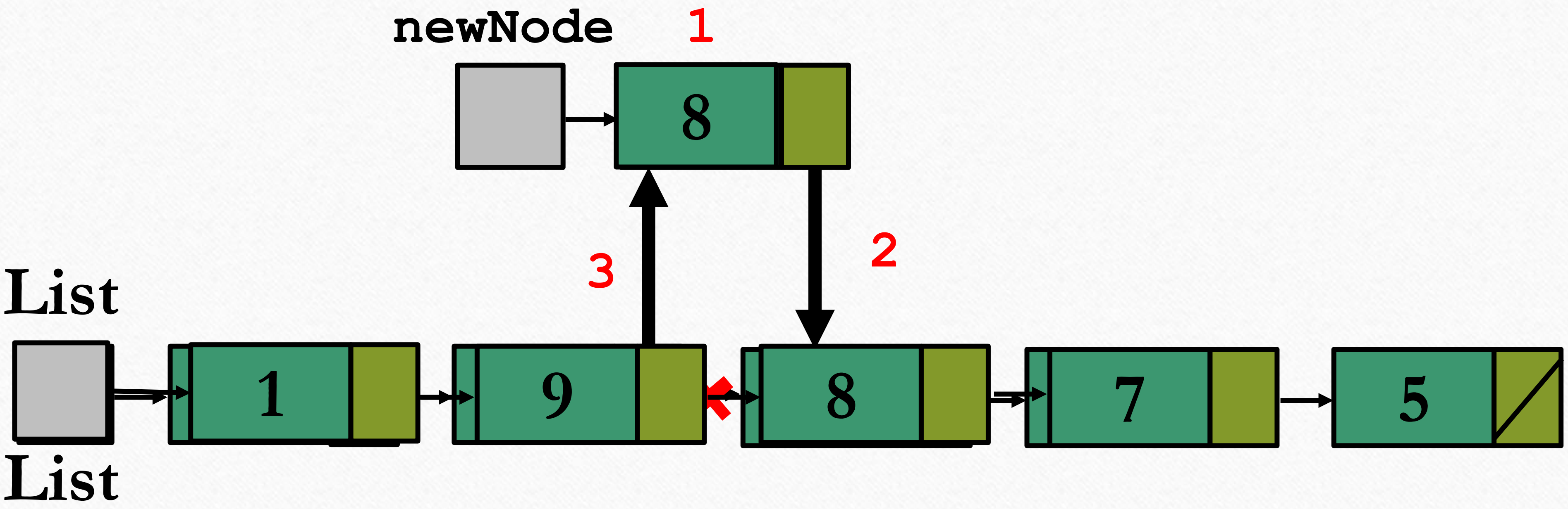
- We are given the reference to a node, and **the new node is inserted after the given node**



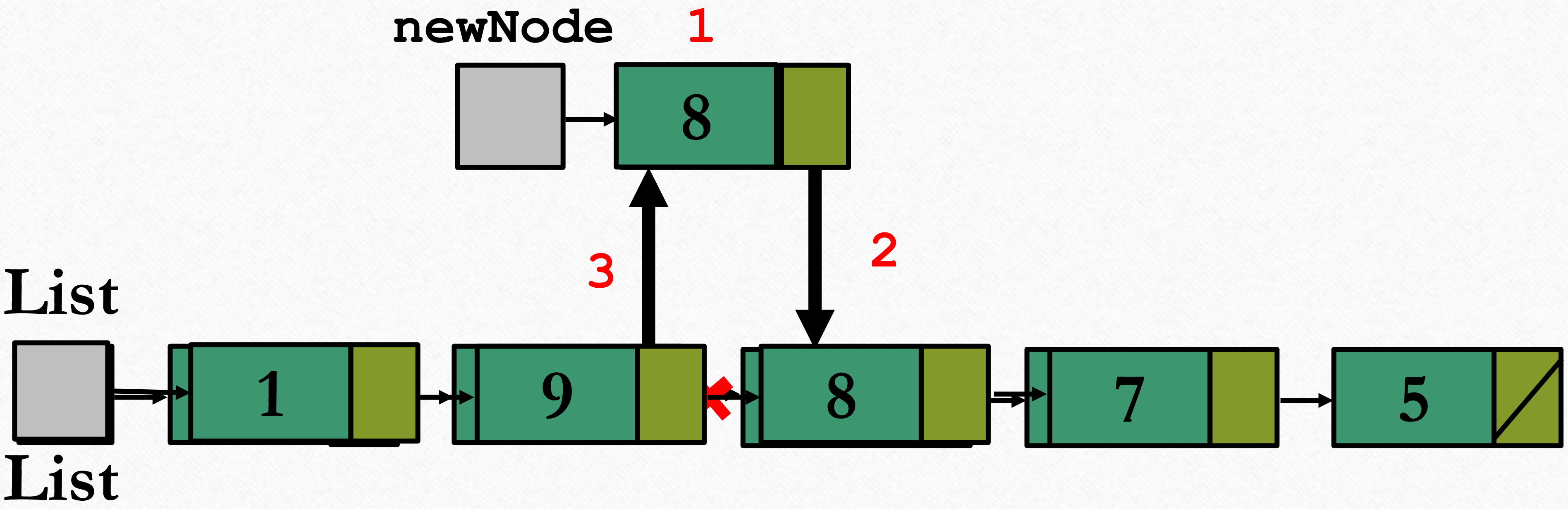
III. Linked-Lists

Implementing the Basic linked list Operations

E. Insert a Node in a Linked List (after a given node)



```
void insertAfter(Node* prevNode, int val){
    Node* newNode = new (Node);
    newNode -> data = val;
    newNode -> next = prevNode -> next;
    prevNode -> next = newNode;
}
```



III. Linked-Lists

Implementing the Basic linked list Operations

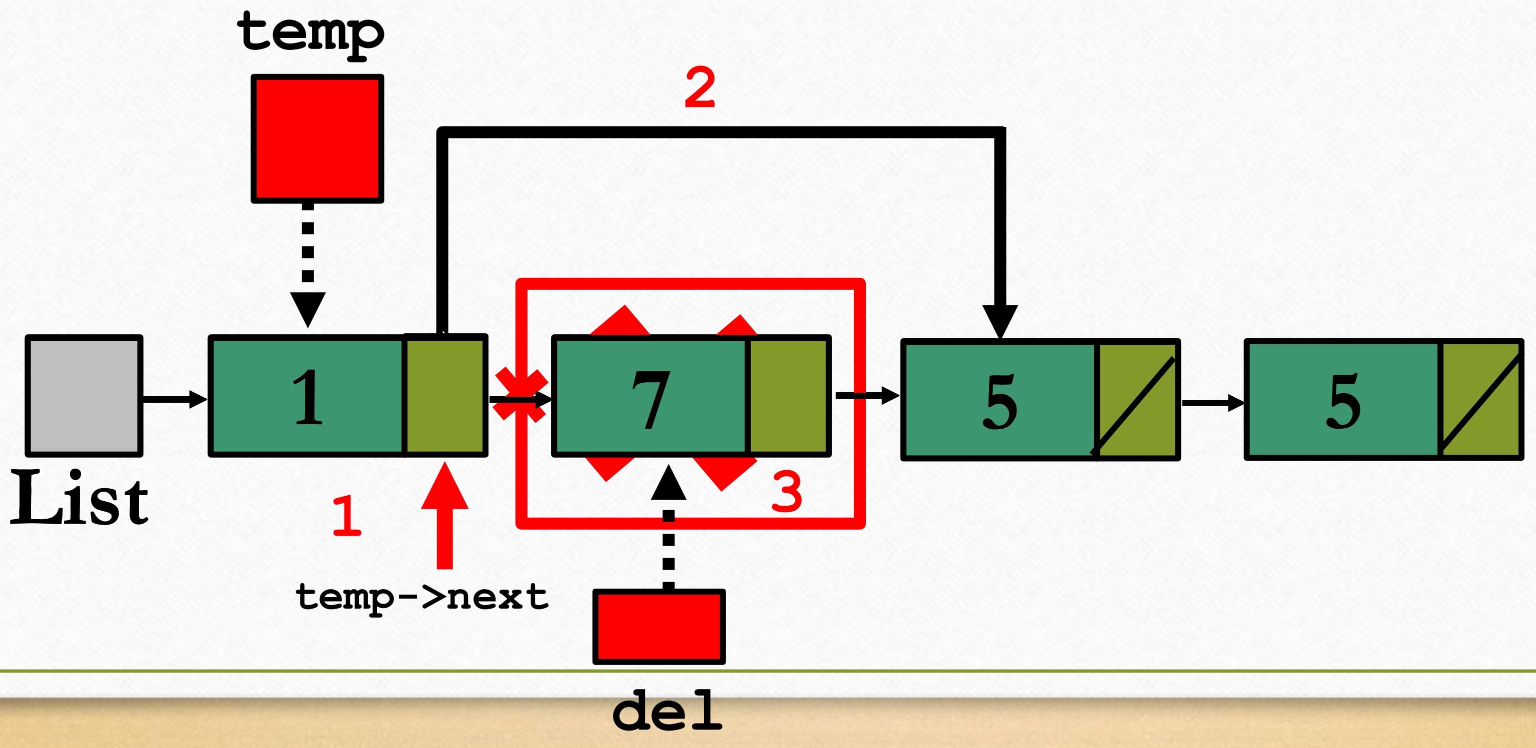
F. Delete a node in a linked list

- To delete a node from a linked list, we need to do these steps
  - **Find the previous node** of the node to be deleted.
  - **Change the next pointer** of the previous node
  - **Free the memory** of the deleted node.
- In the deletion, there is a special case in which the first node is deleted. In this, we need to update the head of the linked list.

III. Linked-Lists

Implementing the Basic linked list Operations

F. Delete a node in a linked list



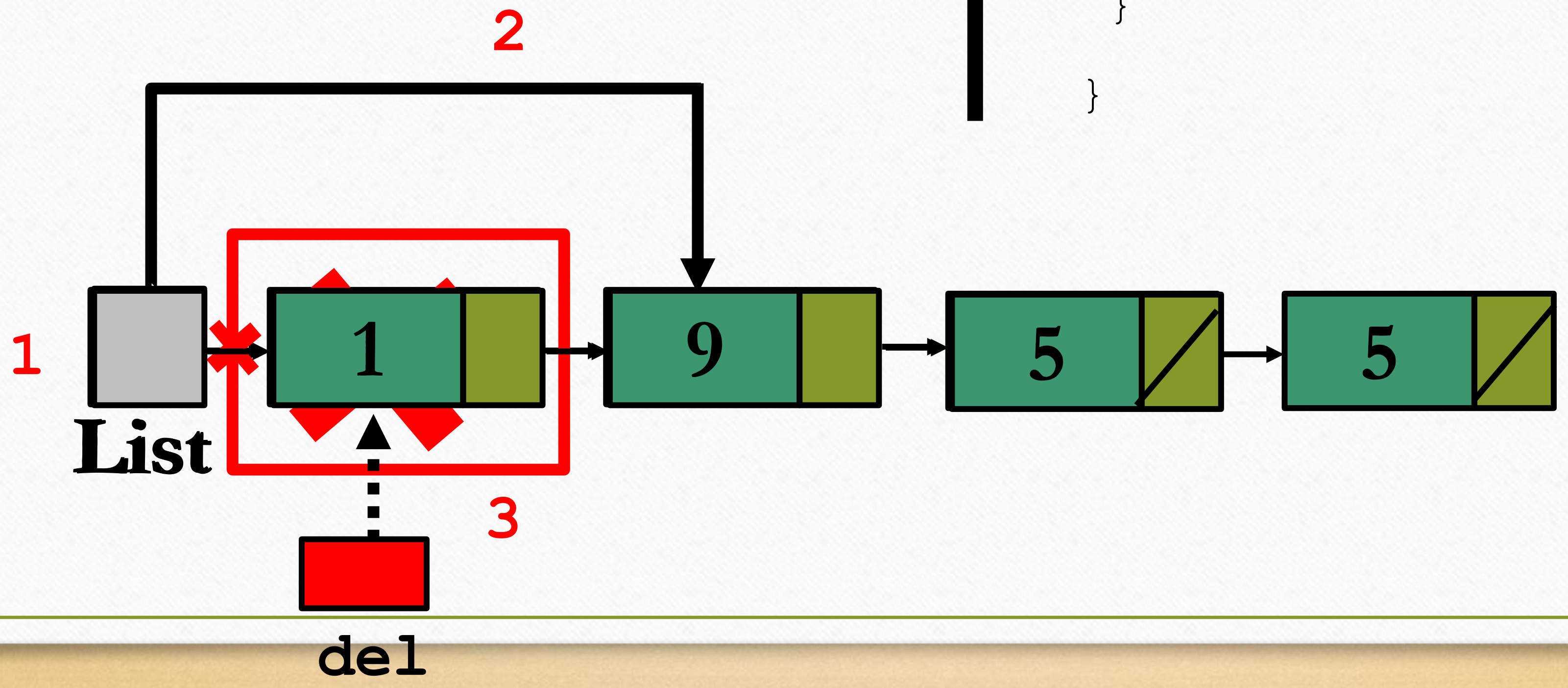
III. Linked-Lists

Implementing the Basic linked list Operations

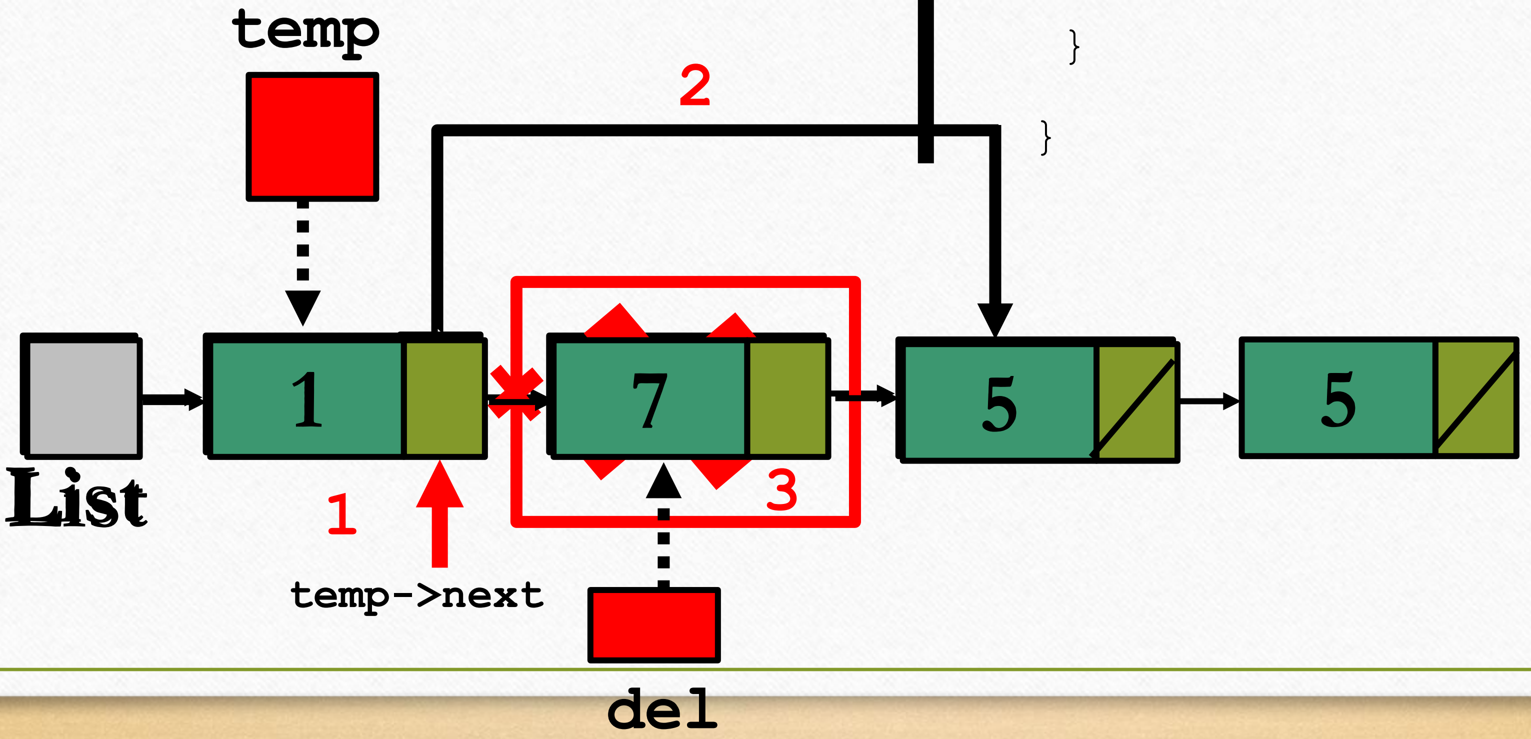
F. Delete a node in a linked list

```
void deleteLL(LIST &List, Node* del){
    if(List == del){
        List = List -> next;
        delete del;
        return;
    }
    LIST temp = List;
    while( temp -> next != NULL ){
        if(temp -> next == del){
            temp -> next = temp->next->next;
            delete del;
            return;
        }
        temp = temp -> next;
    }
}
```

```
void deleteLL(LIST &List, Node* del){
    if(List == del){
        List = List -> next;
        delete del;
        return;
    }
    LIST temp = List;
    while( temp -> next != NULL ){
        if(temp -> next == del){
            temp -> next = temp->next->next;
            delete del;
            return;
        }
        temp = temp -> next;
    }
}
```



```
void deleteLL(LIST &List, Node* del){
    if(List == del){
        List = List -> next;
        delete del;
        return;
    }
    LIST temp = List;
    while( temp -> next != NULL ){
        if(temp -> next == del){
            temp -> next = temp->next->next;
            delete del;
            return;
        }
        temp = temp -> next;
    }
}
```



III. Linked-Lists

Implementing the Basic linked list Operations

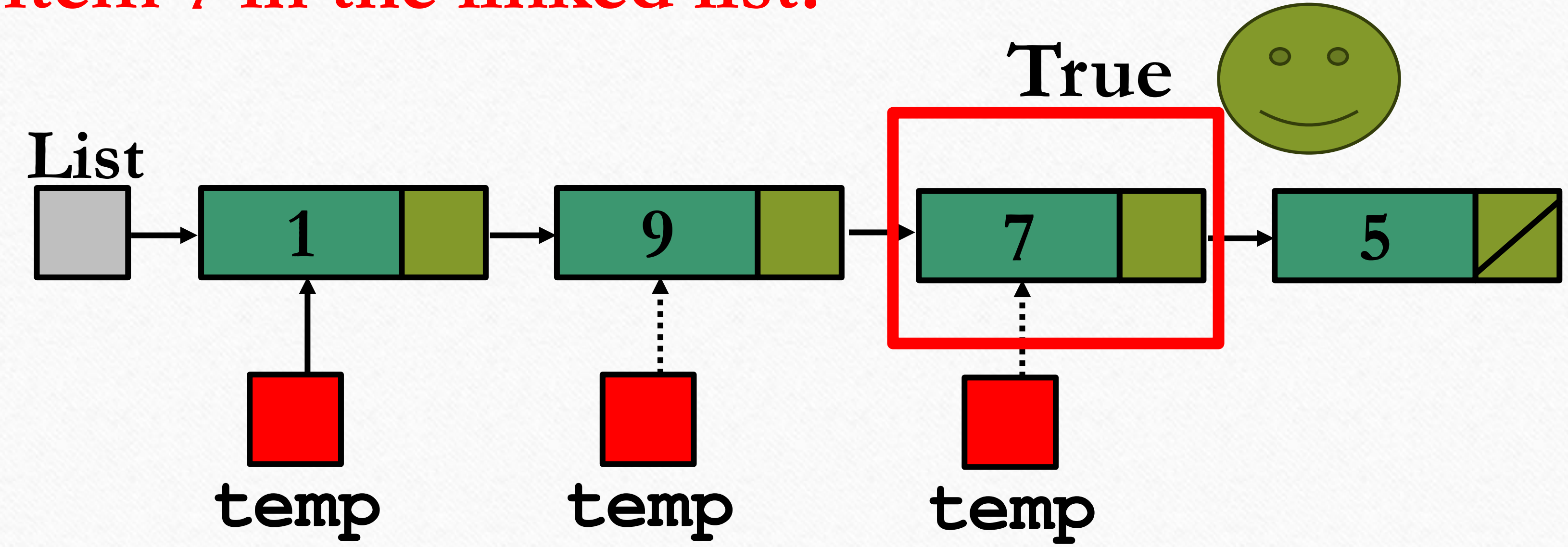
F. Delete a node in a linked list

- To delete a node from a linked list, we need to do these steps
  - **Find the previous node** of the node to be deleted.
  - **Change the next pointer** of the previous node
  - **Free the memory** of the deleted node.
- In the deletion, there is a special case in which the first node is deleted. In this, we need to update the head of the linked list.

G. Linked List node Searching

- To search any value in the linked list, we can **traverse the linked list** and compares the value present in the node.

Is item 7 in the linked list?



III. Linked-Lists

Implementing the Basic linked list Operations

G. Linked List node Searching

```
bool searchLL(LIST List, int val){
  LIST temp = List;
      while( temp != NULL){
          if( temp -> data == val )
              return true;
          temp = temp -> next;
      }
      return false;
}
```

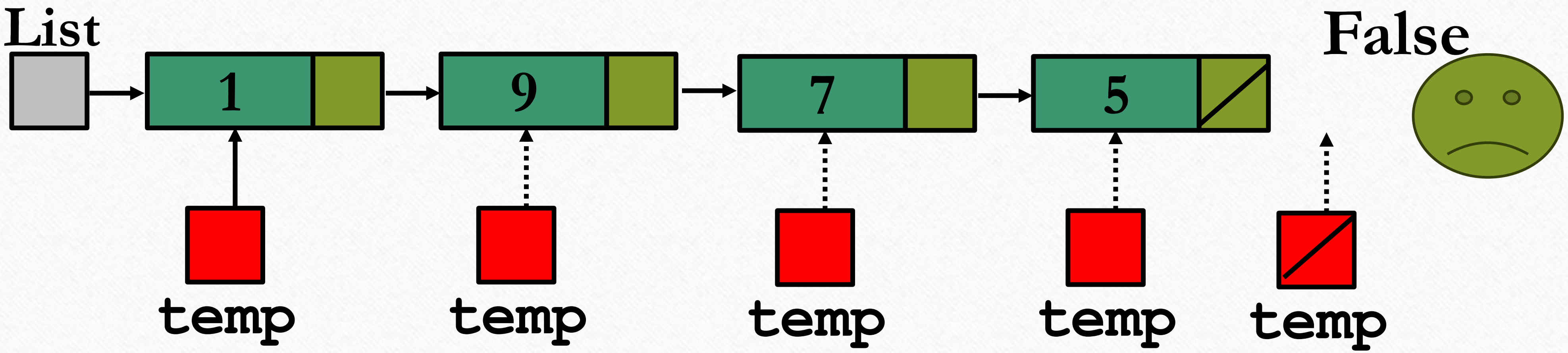
III. Linked-Lists

Implementing the Basic linked list Operations

G. Linked List node Searching

- To search any value in the linked list, we can **traverse the linked list** and compares the value present in the node.

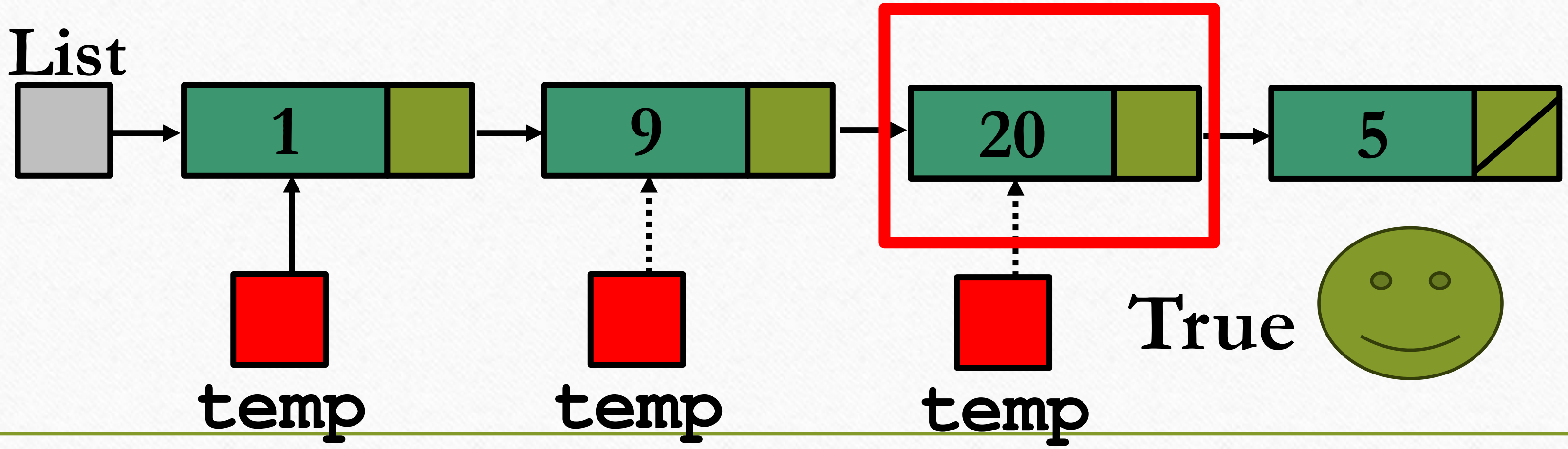
Is item 10 in the linked list?



H. Linked List node Updation

- To update the value of the node, we just need to set the **data part to the new value**.
- Below is the implementation in which we had to update the value of the first node in which data is equal to val and we have to set it to newVal .

Update item 7 in the linked list to 20



III. Linked-Lists

Implementing the Basic linked list Operations

H. Linked List node Updation

```
void updateLL(LIST &List, int val, int newVal){
  LIST temp = List;
  while(temp != NULL){
   if( temp -> data == val){
      temp -> data = newVal;
      return ;
   }
   temp = temp -> next;
  }
}
```

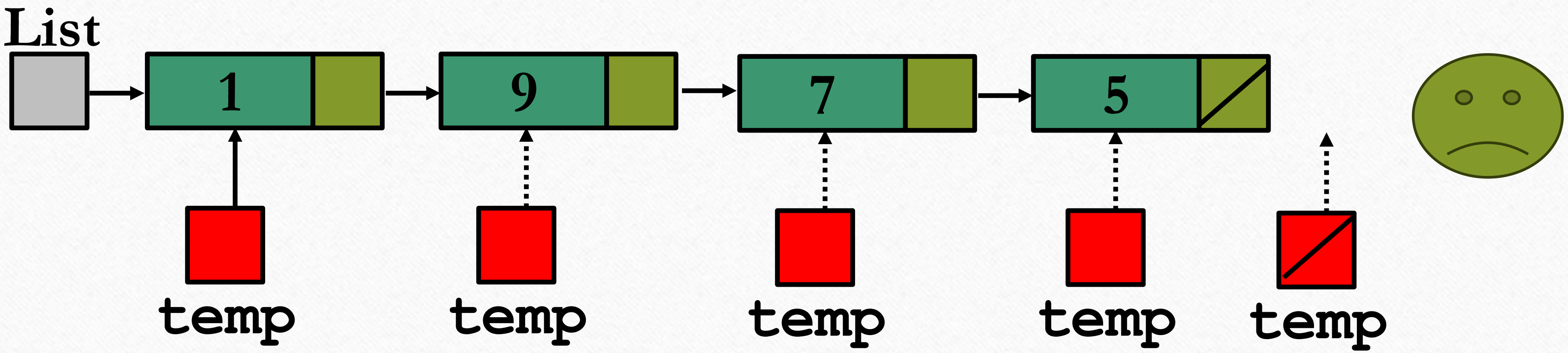
III. Linked-Lists

Implementing the Basic linked list Operations

H. Linked List node Updation

- To update the value of the node, we just need to set the **data part to the new value**.
- Below is the implementation in which we had to update the value of the first node in which data is equal to val and we have to set it to newVal .

Update item 10 in the linked list to 20



III. Linked-Lists

Type of Linked List

Basically, we can put linked lists into the following three items:

- **Singly Linked List**
- **Doubly Linked List**
- **Circular Linked List**

III. Linked-Lists (Type of Linked List)

Singly Linked List

- A Singly-linked list is **a collection of nodes linked together in a sequential way** where each node of the singly linked list **contains a data field and an address field** that contains the reference of the **next node**.
- Elements are traversed in the forward direction.

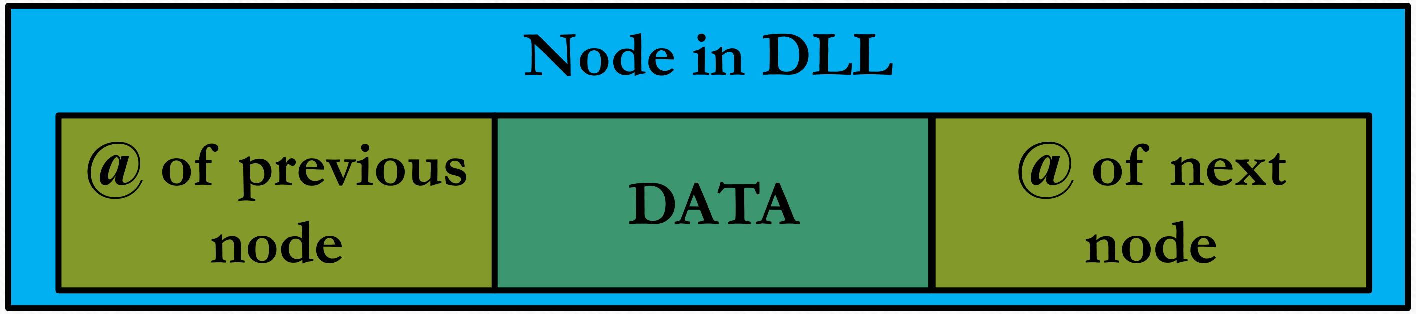
III. Linked-Lists (Type of Linked List)

Doubly Linked List

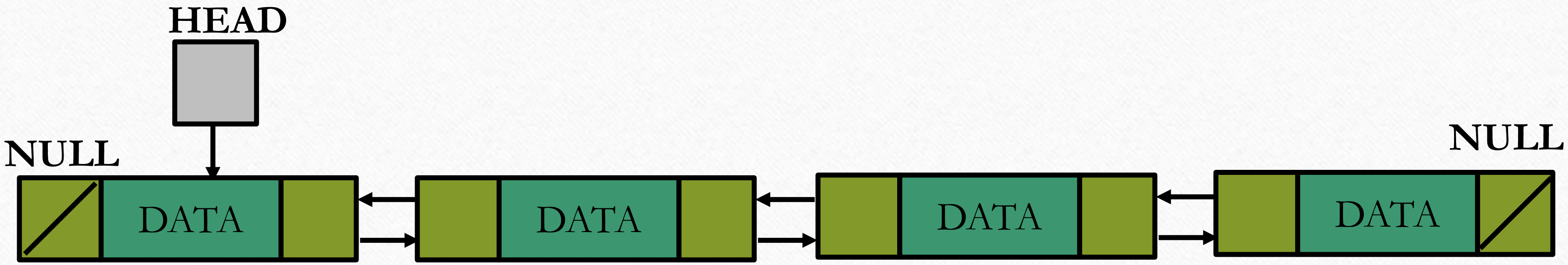
- A Doubly Linked List contains an **extra memory to store the address of the previous node**, together with the address of the next node and data which are there in the singly linked list.
- So, here we are storing the address of the next as well as the previous nodes.
- This pointer **makes it easy to navigate the list in both directions** and thus **simplifies the process of deleting or inserting an element** before the selected one.

III. Linked-Lists (Type of Linked List)

Doubly Linked List



- The nodes are connected to each other in this form where the first node has **prev = NULL** and the last node has **next = NULL**



III. Linked-Lists (Type of Linked List)

Doubly Linked List

- We define a linked list in a struct using the below code:

```
struct DLLNode {
  int data;
  struct DLLNode* prev;
  struct DLLNode* next
};
typedef DLLNode* DLList;
```

III. Linked-Lists (Type of Linked List)

Doubly Linked List

Advantages over Singly Linked List-

- It can be traversed **both** forward and backward direction.
- The delete operation is more efficient if the node to be deleted is given.
- The insert operation is more efficient if the node is given before which insertion should take place.

III. Linked-Lists (Type of Linked List)

Doubly Linked List

Disadvantages over Singly-Linked List

- It will require more space as each node has an extra memory to store the address of the previous node.
- The number of modifications increase while doing various operations like insertion, deletion, etc.

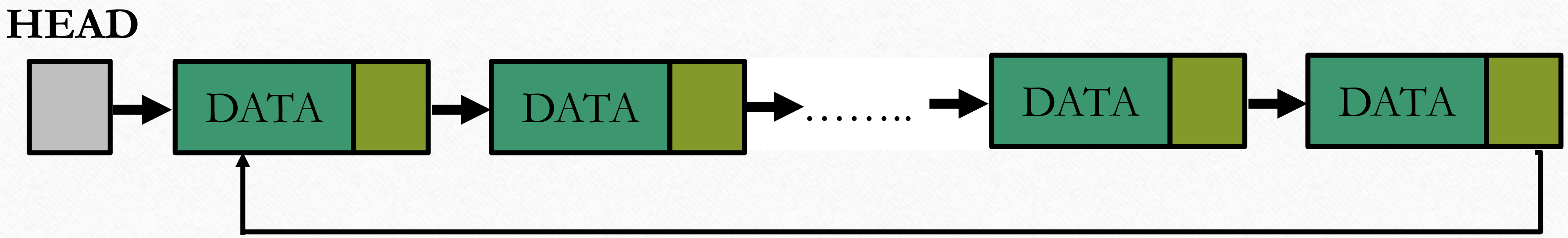
III. Linked-Lists (Type of Linked List)

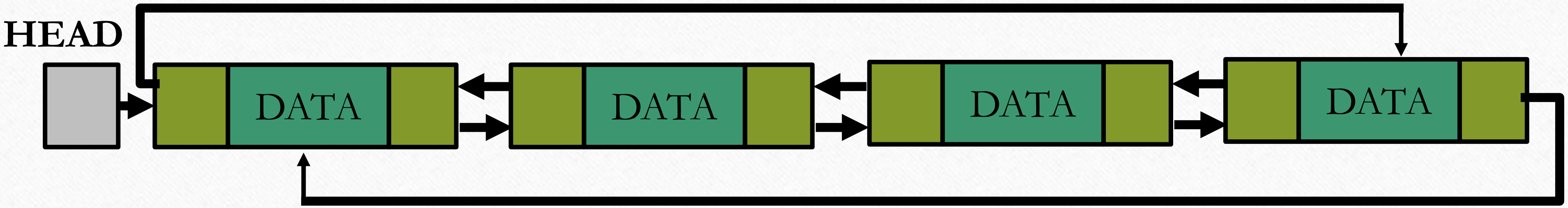
Circular Linked List

- A circular linked list is **either a singly or doubly linked list** in which there are no **NULL** values.
- Here, we can implement the Circular Linked List by making the use of Singly or Doubly Linked List.
- In the case of a **singly** linked list, **the next of the last node contains the address of the first node** and in case of a **doubly-linked** list, **the next of last node contains the address of the first node** and **previous** of the first node contains the address of the **last node**.

III. Linked-Lists (Type of Linked List)

Circular Linked List





III. Linked-Lists (Type of Linked List)

Circular Linked List

Advantages of a Circular linked list

- The list can be **traversed from any node**.
- Circular lists are the required data structure when we want a list to be accessed in a circle or loop.
- We can **easily traverse to its previous node** in a circular linked list, which is **not possible in a singly linked list**.

III. Linked-Lists (Type of Linked List)

Circular Linked List

Disadvantages of Circular linked list

- If not traversed carefully, then we could end up in an **infinite loop** because here we don't have any **NULL** value to stop the traversal.
- **Operations** in a circular linked list **are complex** as compared to a singly linked list and doubly linked list **like reversing a circular linked list**, etc.

III. Linked-Lists (Type of Linked List)

Linked Lists Versus Arrays

- In general, the main advantage of arrays over linked list is that arrays allow random access to any element in $\boldsymbol{O(1)}$ and whereas linked-lists allow only sequential access.
- Hence, in an array search can be performed on sorted data in $\boldsymbol{O(log\, n)}$ whereas it takes $\boldsymbol{O(n)}$ in the case of a linked list.
- **In almost all other cases linked-list is a better choice.**

III. Linked-Lists (Type of Linked List)

Linked Lists Versus Arrays

- The following tables summarize tradeoffs between arrays and linked-lists:

	Array	Linked-list
extra storage needed for storing addresses	no	yes
allocation/deallocation for each element	no	yes
tail sharing	no	yes (singly-linked list only)

IV. Stacks

- Stack is a data structure that can be used to store data which can later be retrieved in the reverse or **LIFO** (Last In First Out) or **FILO** (First In Last Out) **order**.
- Stack is an ordered-list in which all the **insertions** and **deletions** are made **at the same end to maintain** the **LIFO** order called the **top**.
- Real-life examples of a stack are a deck of cards, piles of books, piles of money, and many more.

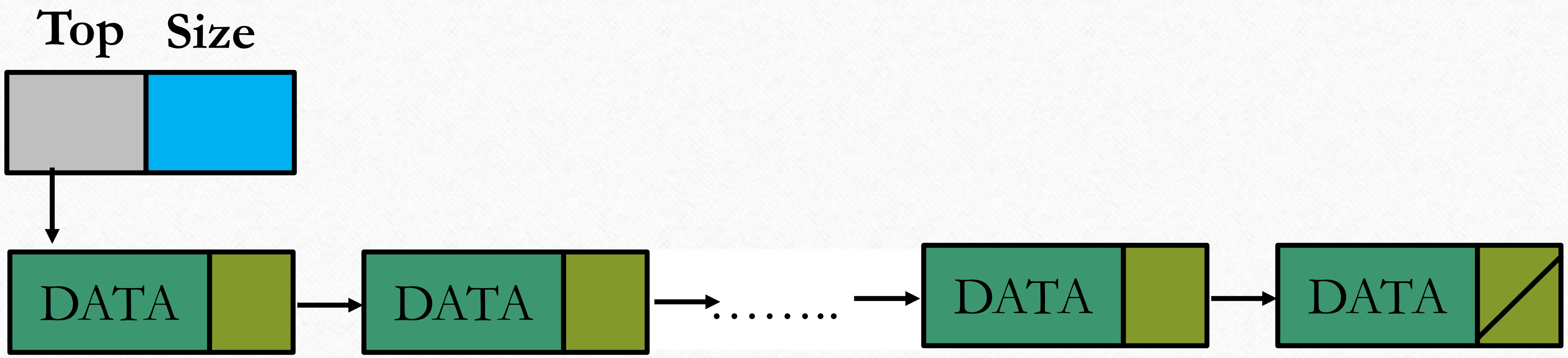


IV. Stacks

- Most **microprocessors use a stack-based architecture**.
- When a **function is called,** its return address and arguments are pushed onto a stack and when that function terminates, those values are popped off from the stack.
- These stack operations are built into microprocessors.
- Note that **one danger in recursive programming** is that the stack that keeps return address and arguments could **overflow** if too many recursive calls are made.

IV. Stacks

➢ Stack Representation :



IV. Stacks

Declaration

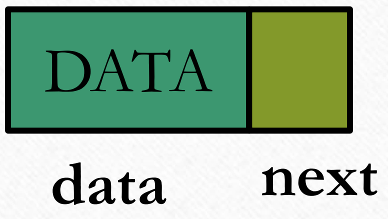
The creation of a structure with :

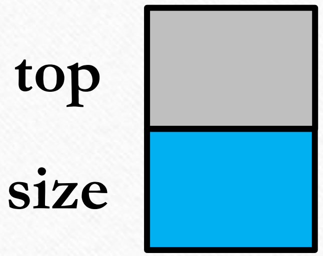
- A "**top**" field representing the **add** or **delete** position, and
- A "**size**" field representing the stack size.

IV. Stacks

Declaration

```
struct Node {
     int data;
     struct Node* next;
};
typedef struct  {
     struct Node *top;
     int size;
} STACK;
```





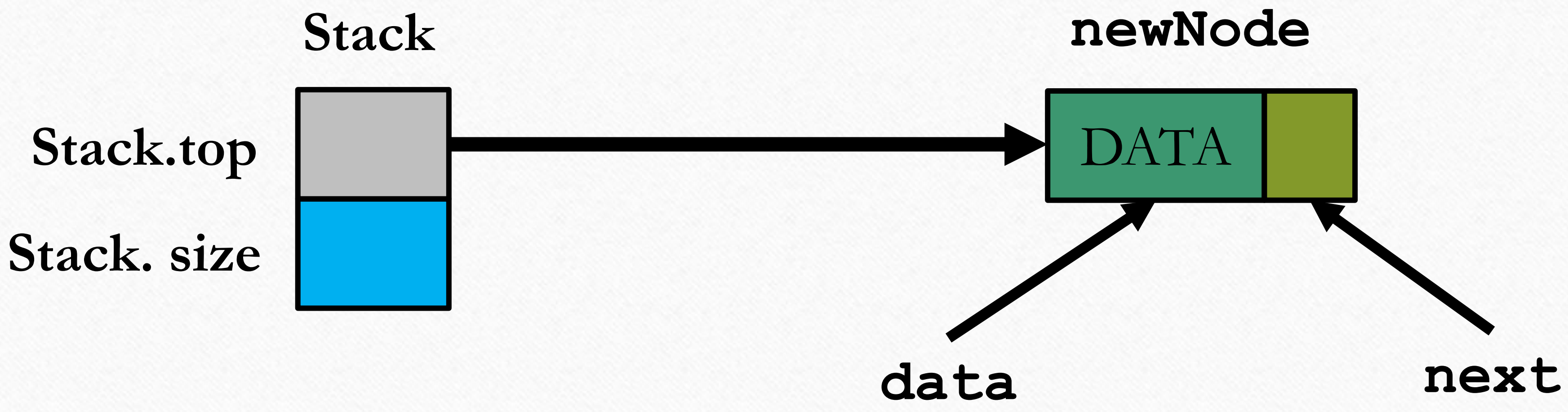
- Now, we might have a variable of type **STACK** called **Stack**:

```
STACK Stack;
```

IV. Stacks

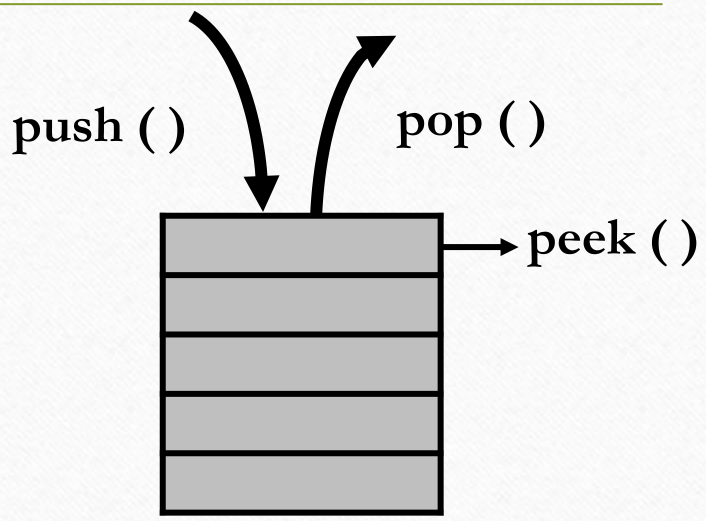
Declaration (Examlpe)

```
STACK Stack;
Node *newNode = new Node;
Stack = newNode;
```



IV. Stacks

Implementing Stack Operations

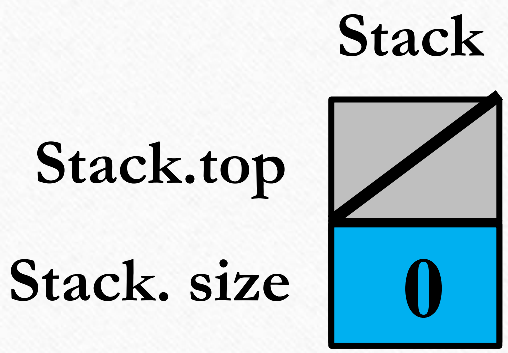


The operations defined on a stack are:

- **isEmpty** : Check if the stack is empty
- **isFull** : Check if the stack is full
- **Size**: Returns the number of elements in the stack.
- **push** : Adds an element to the top of the stack
- **peek** : Examine the top element in the stack
- **pop**: Removes and returns the element at the top of the stack

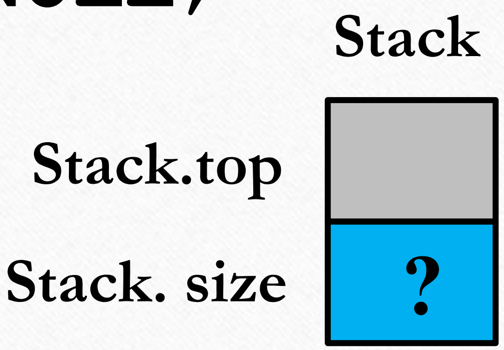
IV. Stacks (Implementing Stack Operations)

```
// Function to initialize the Stack
    STACK init_Stack(){
        STACK Stack;
        Stack.top = NULL;
        Stack.size = 0;
        return Stack;
    }
```



IV. Stacks (Implementing Stack Operations)

```
// Function to check if the Stack is empty or not
   bool isEmpty(STACK Stack) {
        return Stack.top == NULL;
   }
```

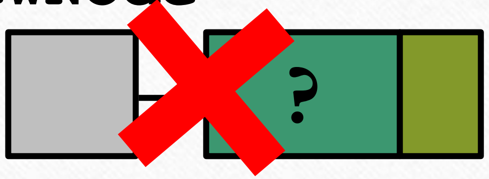


IV. Stacks (Implementing Stack Operations)

```
// Function to check if the Stack is full or not
    bool isFull(){
        Node *newNode = new Node;   //create new node
        if(newNode == NULL){
            cout << "\nStack is Full " << endl;
            return true;
        }
        else{
            delete newNode;
            return false;
        }
    }
```

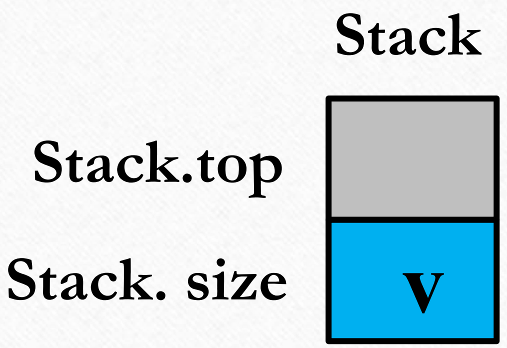
No Space

newNode



IV. Stacks (Implementing Stack Operations)

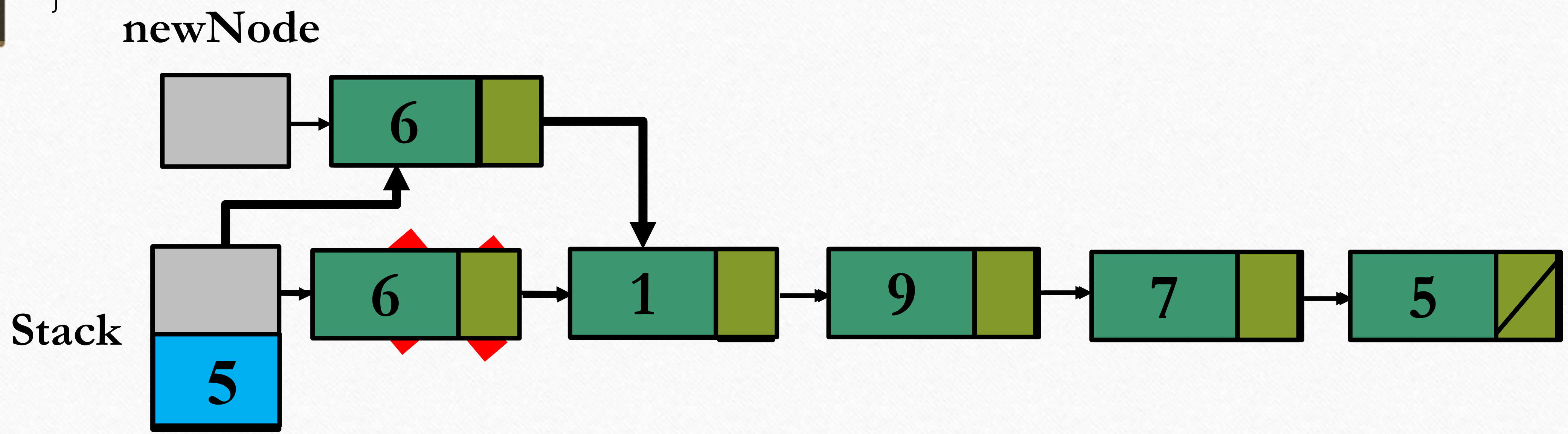
```
//Function to return Stack Size

    int Size(STACK Stack) {
        return Stack.size;
    }
```



IV. Stacks (Implementing Stack Operations)

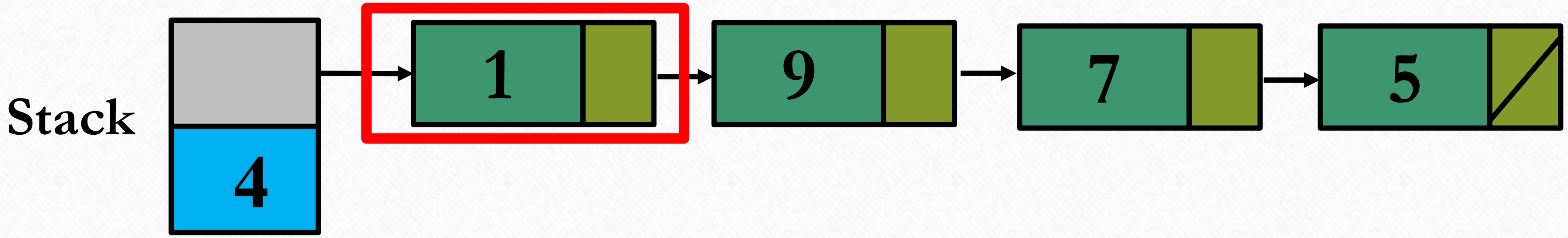
```
// Function to push an element onto the Stack
  void push(STACK &Stack, int val){
      if (isFull()){
          return;
      }
      Node *newNode = new Node;
      newNode -> data = val;
      newNode -> next = Stack.top;
      Stack.top = newNode;
      Stack.size++;
  }
```

```
void push(STACK &Stack, int val){
     if (isFull()){
          return;
     }
     Node *newNode = new Node;
     newNode -> data = val;
     newNode -> next = Stack.top;
     Stack.top = newNode;
     Stack.size++;
}
```



IV. Stacks (Implementing Stack Operations)

```
// Function to return the top element of the Stack
int peek(STACK Stack) {
    if (!isEmpty(Stack))
        return Stack.top -> data;
    else {
        cout << "Stack is Empty" << endl;
        return -1;
    }
}
```

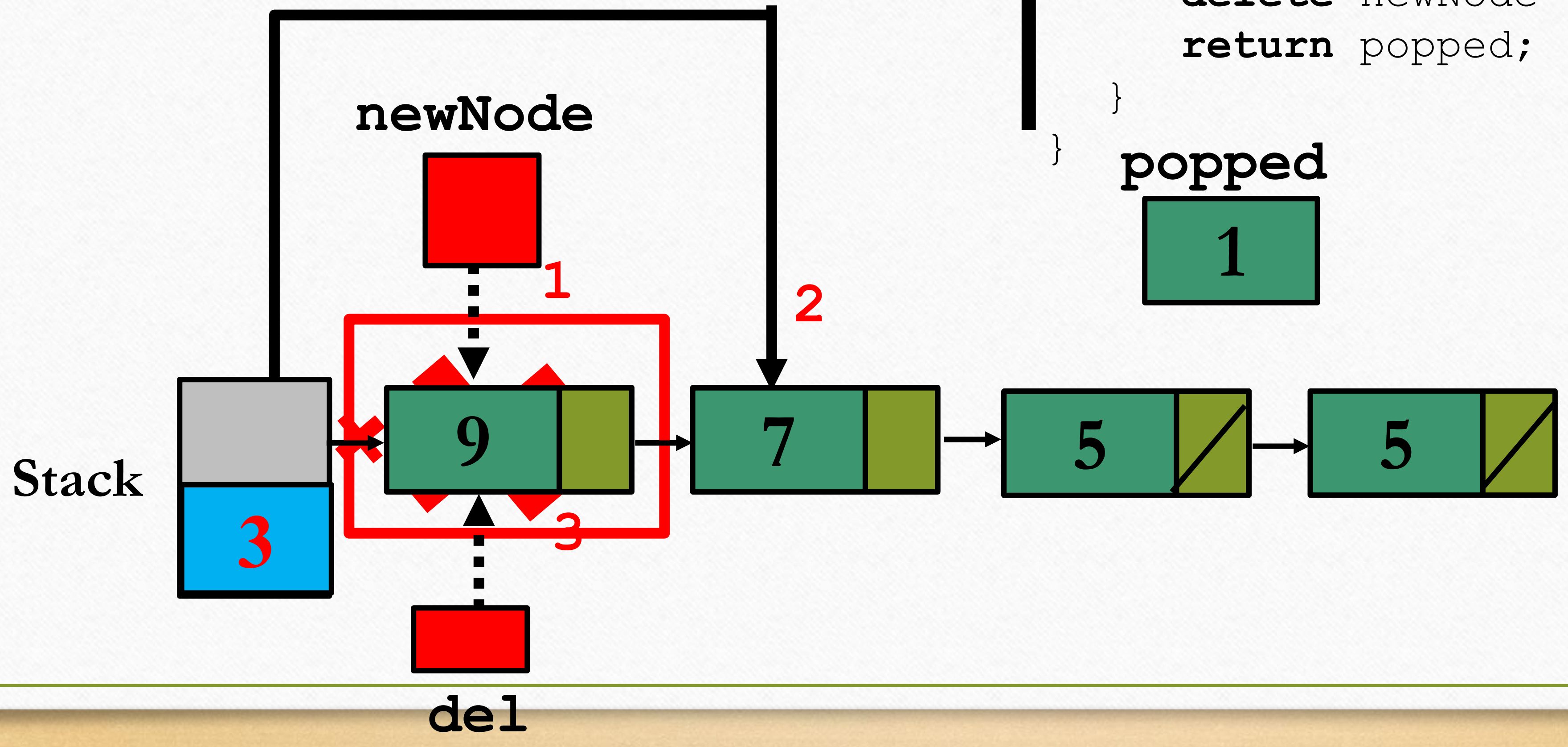


IV. Stacks (Implementing Stack Operations)

```
// Function to remove the top element from the Stack

int pop(STACK &Stack){
  if (isEmpty(Stack)) {
    cout << "Stack is Empty"
          << endl;
    return -1;
  }
else{
    Node* newNode;
    int popped = peek(Stack);
    cout << "Popped Element = "
          << popped << endl;
    newNode = Stack.top;
    Stack.top = Stack.top -> next;
    Stack.size--;
    delete newNode ;
    return popped;
  }
}
```

```
int pop(STACK &Stack){
  if (isEmpty(Stack)) {
   cout << "Stack is Empty"<< endl;
   return -1;
 }
```

```
else{
    Node* newNode;
    int popped = peek(Stack);
    cout << "Popped Element = "
           << popped << endl;
    newNode = Stack.top;
    Stack.top = Stack.top -> next;
    Stack.size--;
    delete newNode ;
    return popped;
 }
}
```

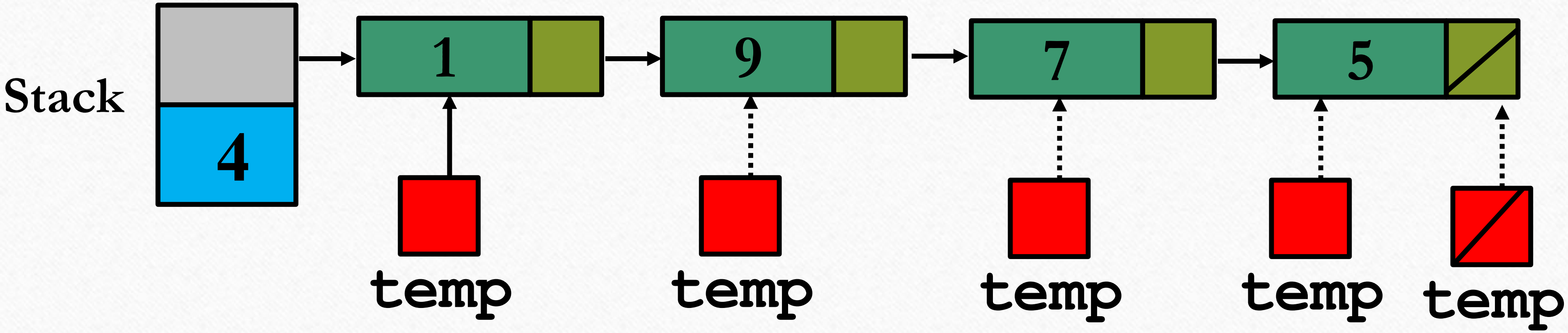


IV. Stacks (Implementing Stack Operations)

```
// Display all elements of the Stack
void display(STACK Stack){
    Node *nowNode = Stack.top;
    while(nowNode != NULL){
        cout << nowNode -> data << "-->";
        nowNode = nowNode -> next;
    }
    cout << "NULL" << endl;
}
```

```
void display(STACK Stack){
    Node *nowNode = Stack.top;
    while(nowNode != NULL){
        cout << nowNode -> data << "-->";
        nowNode = nowNode -> next;
    }
    cout << "NULL" << endl;
}
```

1--> 9--> 7--> 5--> NULL



IV. Stacks

Stack Complexity Analysis

Function	Time Complexity	Auxiliary Space Complexity
isEmpty()	$\mathcal{O}(1)$	$\mathcal{O}(1)$
isFull()	$\mathcal{O}(1)$	$\mathcal{O}(1)$
Size()	$\mathcal{O}(1)$	$\mathcal{O}(1)$
peek()	$\mathcal{O}(1)$	$\mathcal{O}(1)$
push()	$\mathcal{O}(1)$	$\mathcal{O}(1)$
pop()	$\mathcal{O}(1)$	$\mathcal{O}(1)$
display()	$\mathcal{O}(n)$	$\mathcal{O}(1)$

V. Queues

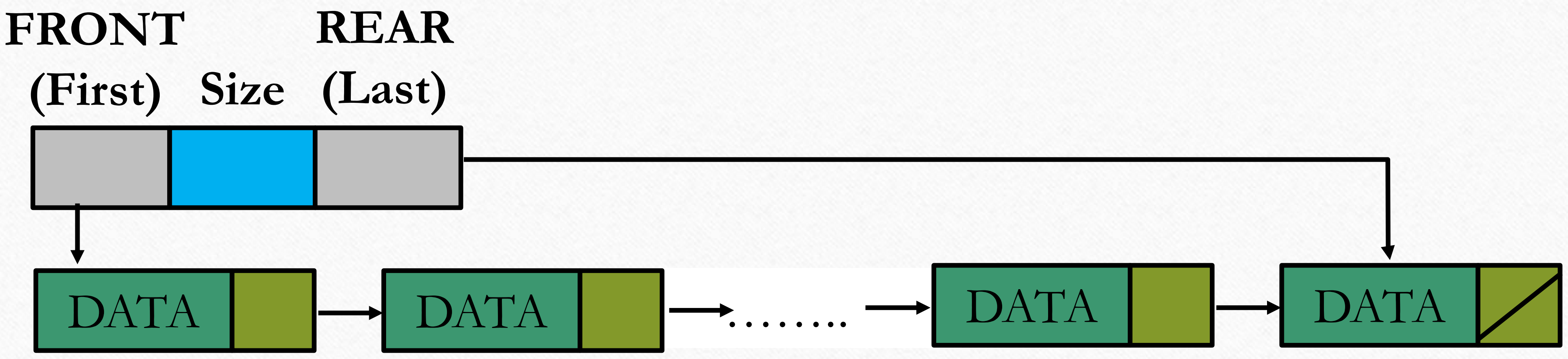
- The queue is also **a list**, with insertion at **one end and deletion at the other**.
- In a queue data structure, the insertion operation is performed at a position which is known as '**rear**' and the deletion operation is performed at a position which is known as '**front**'.
- It's also called as **FIFO** (First In First Out) or **FCFS** (first-come-first-served) basis which means the element, meaning that the element inserted first will be removed first from the queue.

V. Queues

- As in the case of the **queue of people at the ticket window** where newcomers **join the queue at the tail or rear end** of the queue and **service is provided to the one at the front or head** of the queue,
- in the queue data structure **insertions and deletions are made at two different ends** (compare it with stack where these two operations are performed at the same end) **to maintain the FIFO order.**

V. Queues

Queue representation



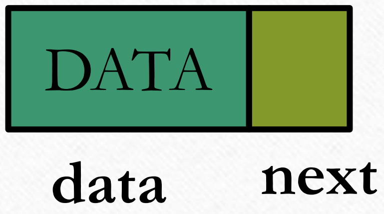
V. Queues

Declaration

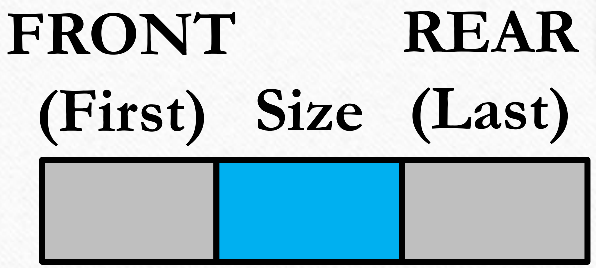
- The creation of a structure with a “**top**” field representing the **add or delete position,** and a “**size**” field representing the queue size.

V. Queues

Declaration




```
struct Node {
    int data;
    struct Node* next;
};
typedef struct  {
    struct Node *first, *last;
    int size;
} QUEUE;
```



➢ Now, we might have a variable of type **QUEUE** called **Queue**:

```
QUEUE Queue;
```

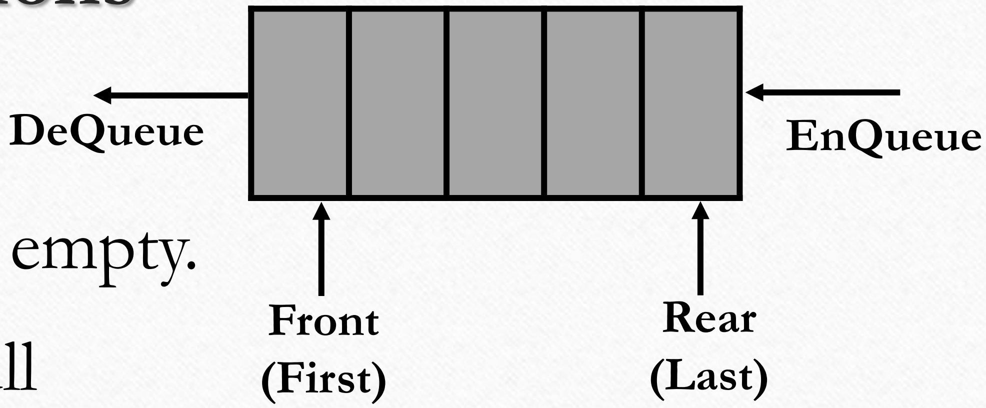
IV. Stacks

Declaration (Examlpe)

```
QUEUE Queue;
Node *newNode = new Node;
Queue.first= newNode;
Queue.last = newNode;
Queue.last->next = NULL;
```

V. Queues

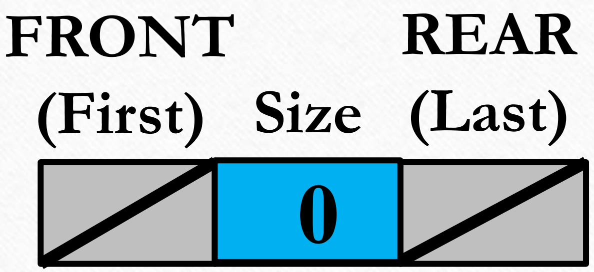
Implementing Queue Operations



- **isEmpty:** Checks if the queue is empty.
- **Is_Full:** check if the Queue is full
- **EnQueue:** Adds a new element to the queue.
- **DeQueue:** Removes and returns the first (front) element from the queue.
- **Size:** Finds the number of elements in the queue.

V. Queues (Implementing Queue Operations)

```
// Function to initialize the Queue
   QUEUE init_Queue(){
        QUEUE Queue;
        Queue.first = NULL;          //Front
        Queue.last = NULL;           //Rear
        Queue.size = 0;
        return Queue;
}
```



V. Queues (Implementing Queue Operations)

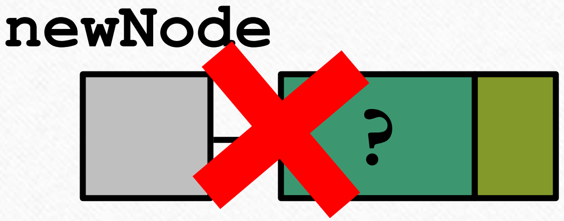
```
// Function to check if the stack is empty or not
   bool isEmpty(QUEUE Queue){
       return Queue.first == NULL;
   }
```

FRONT (First) Size REAR (Last)

V. Queues (Implementing Queue Operations)

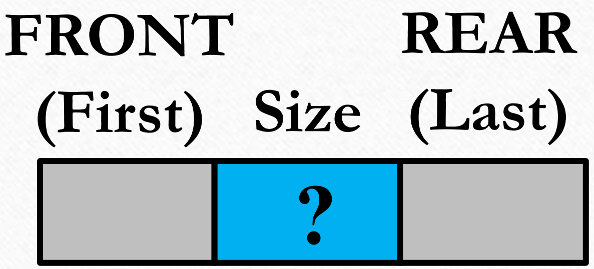
```
// Function to check if the Queue is full or not
    bool isFull(){
        Node *newNode = new Node;   //create new node
        if(newNode == NULL){
            cout << "\nQueue is Full " << endl;
            return true;
        }
        else{
            delete newNode;
            return false;
        }
    }
```

No Space



V. Queues (Implementing Queue Operations)

```
//Function to return Queue Size
   int Size(QUEUE Queue) {
      return Queue.size;
   }
```

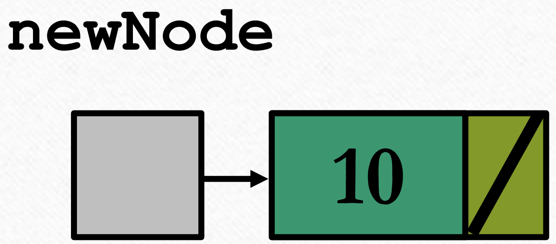


V. Queues (Implementing Queue Operations)

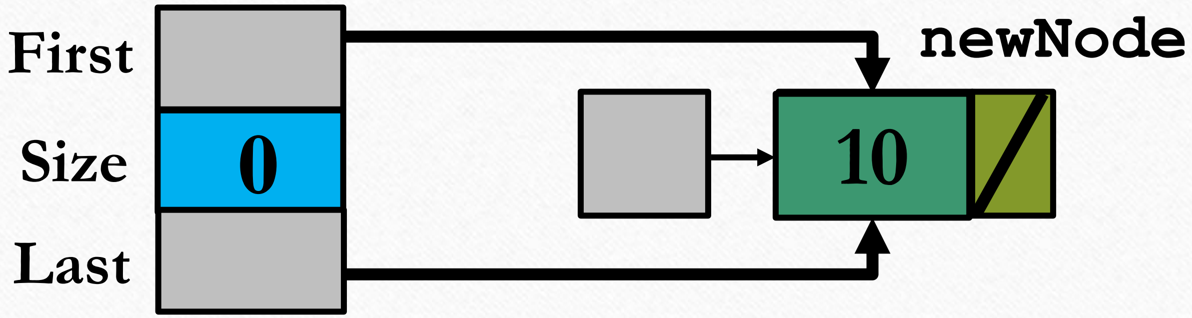
```
// Function to add an element to the Queue
void EnQueue(QUEUE &Queue, int val) {
  if (isFull()){
      return;
  }
  Node *newNode = new Node;
  newNode -> data = val;
  newNode -> next = NULL;

  if(isEmpty(Queue)){
   Queue.first = newNode;
   Queue.last = newNode;
  }
  else{
   Queue.last -> next = newNode ;
   Queue.last = newNode;
  }
  Queue.size++;
}
```

```
void EnQueue(QUEUE &Queue, int val) {
 if (isFull()){
     return;
 }
 Node *newNode = new Node;
 newNode -> data = val;
 newNode -> next = NULL;
```

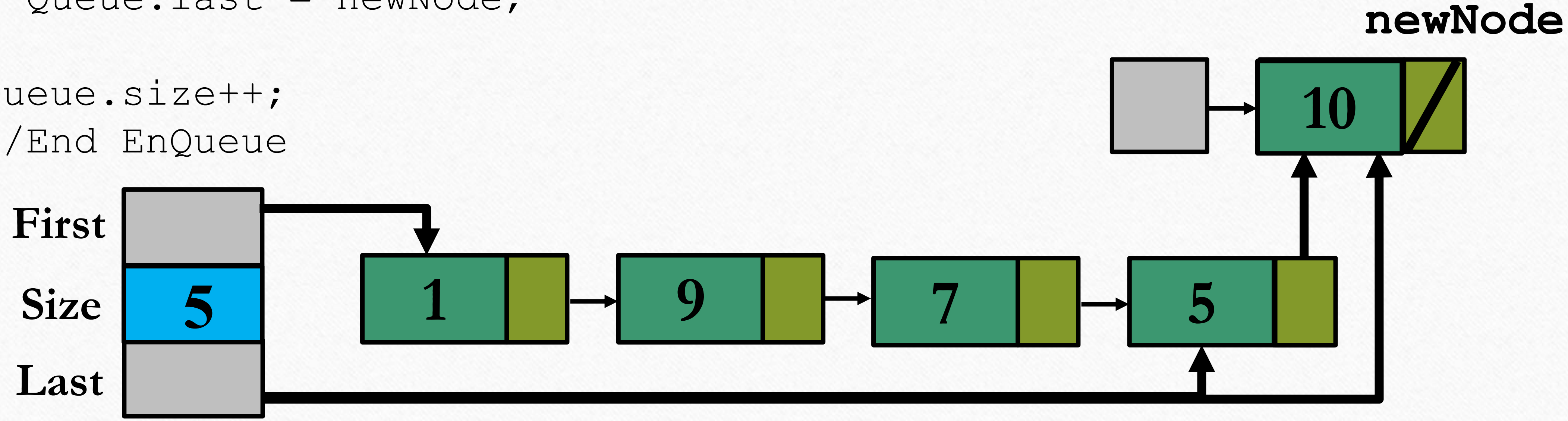
No Space



```
void EnQueue(QUEUE &Queue, int val) {

 if(isEmpty(Queue)){
   Queue.first = newNode;
   Queue.last = newNode;
 }
 else{
   Queue.last -> next = newNode ;
   Queue.last = newNode;
 }
 Queue.size++;
}//End EnQueue
```



```
void EnQueue(QUEUE &Queue, int val) {
//////////////////
 if(isEmpty(Queue)){
   Queue.first = newNode;
   Queue.last = newNode;
 }
 else{
   Queue.last -> next = newNode ;
   Queue.last = newNode;
 }
 Queue.size++;
}//End EnQueue
```

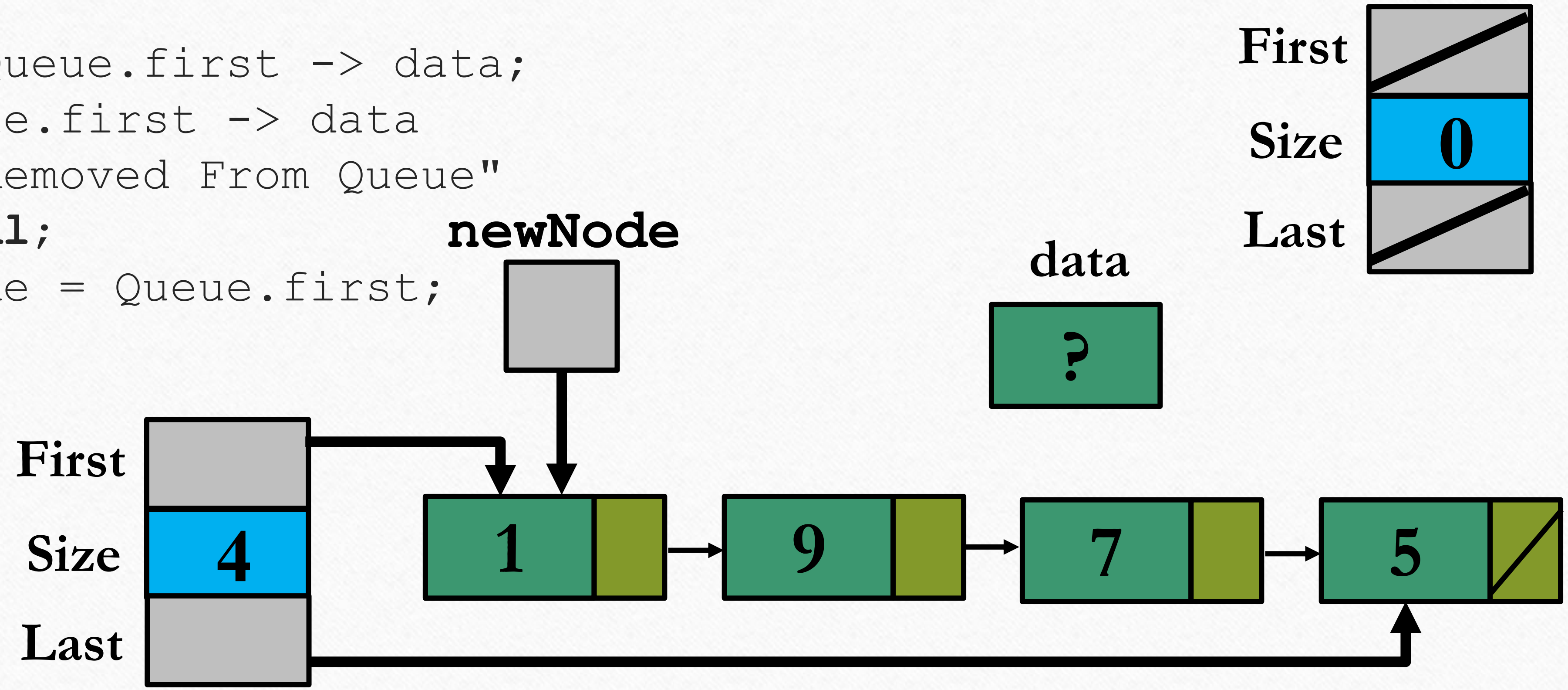


V. Queues (Implementing Queue Operations)

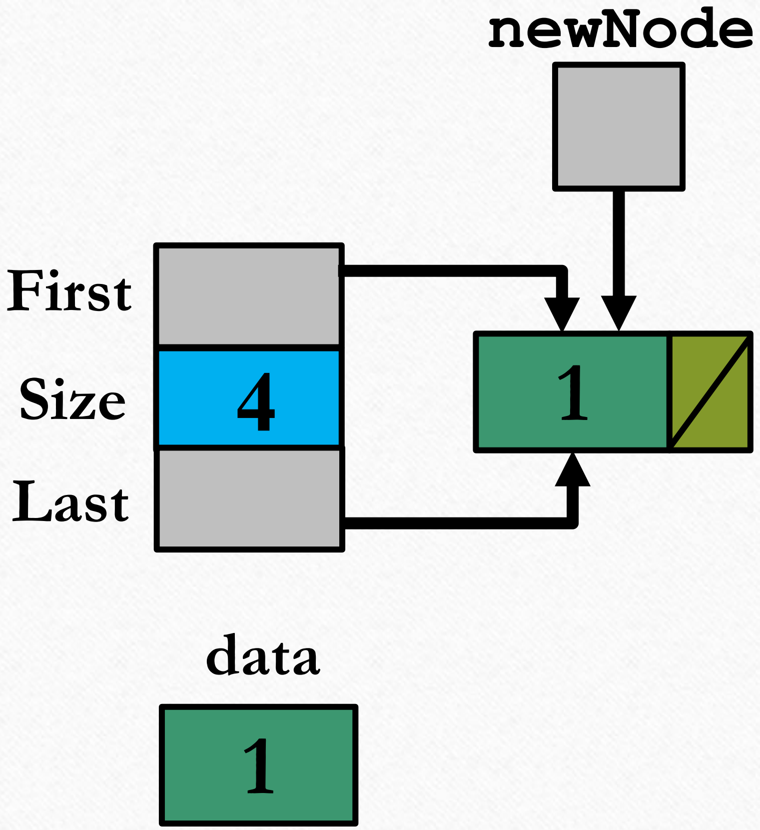
```
// Function to remove an element from the Queue
int DeQueue(QUEUE &Queue) {
if(isEmpty(Queue)){
    cout << "Queue is Empty"
         << endl;
    return 0;
}
int data = Queue.first -> data;
cout << Queue.first -> data
     << " Removed From Queue"
     << endl;
Node *newNode = Queue.first;
if (Queue.first == Queue.last){
   Queue.first = Queue.last = NULL;
}
else {
Queue.first = Queue.first -> next;
}
Queue.size--;
delete newNode;
return data;
}
```

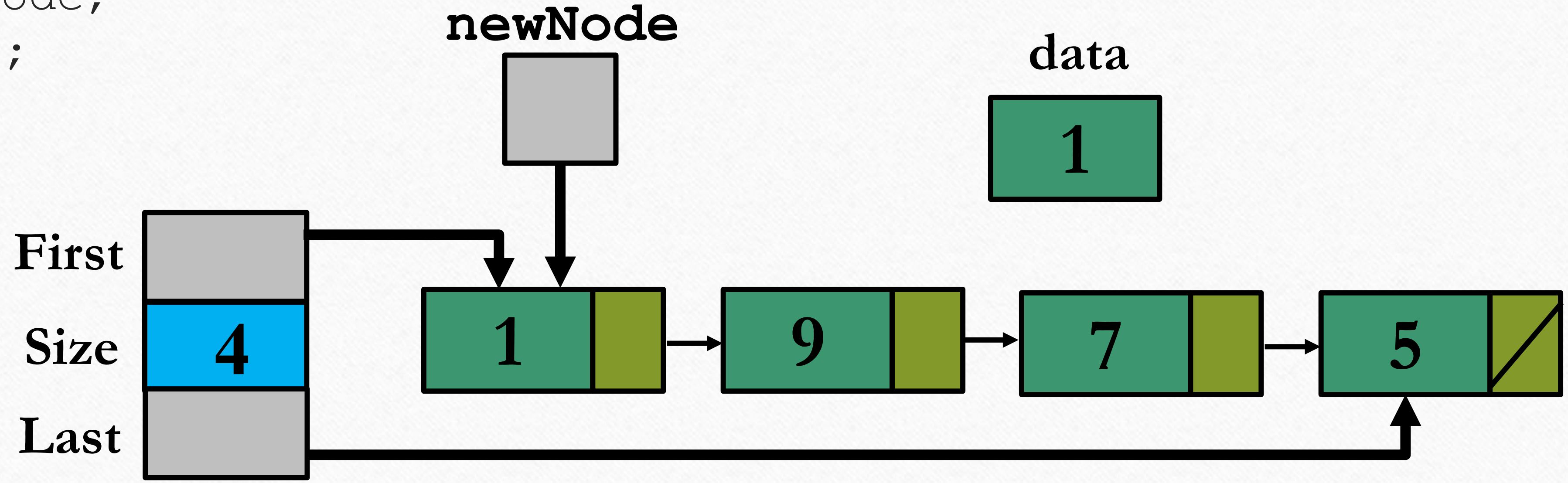
```
int DeQueue(QUEUE &Queue) {
if(isEmpty(Queue)){
    cout << "Queue is Empty"
         << endl;
    return 0;
}

int data = Queue.first -> data;
cout << Queue.first -> data
      << " Removed From Queue"
      << endl;
Node *newNode = Queue.first;
```

Removed From Queue

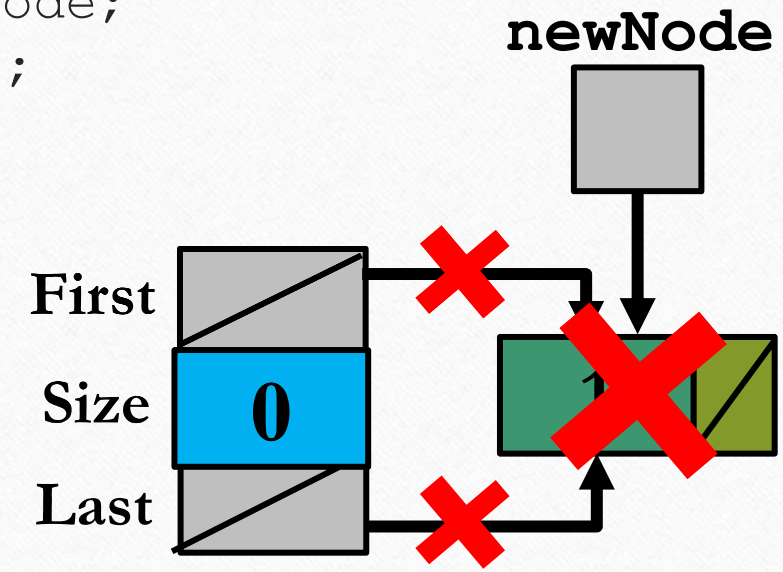


```
int DeQueue(QUEUE &Queue) {
//////////////////
if (Queue.first == Queue.last){
    Queue.first = Queue.last = NULL;
 }
 else {
 Queue.first = Queue.first -> next;
 }
  Queue.size--;
 delete newNode;
 return data;
}
```

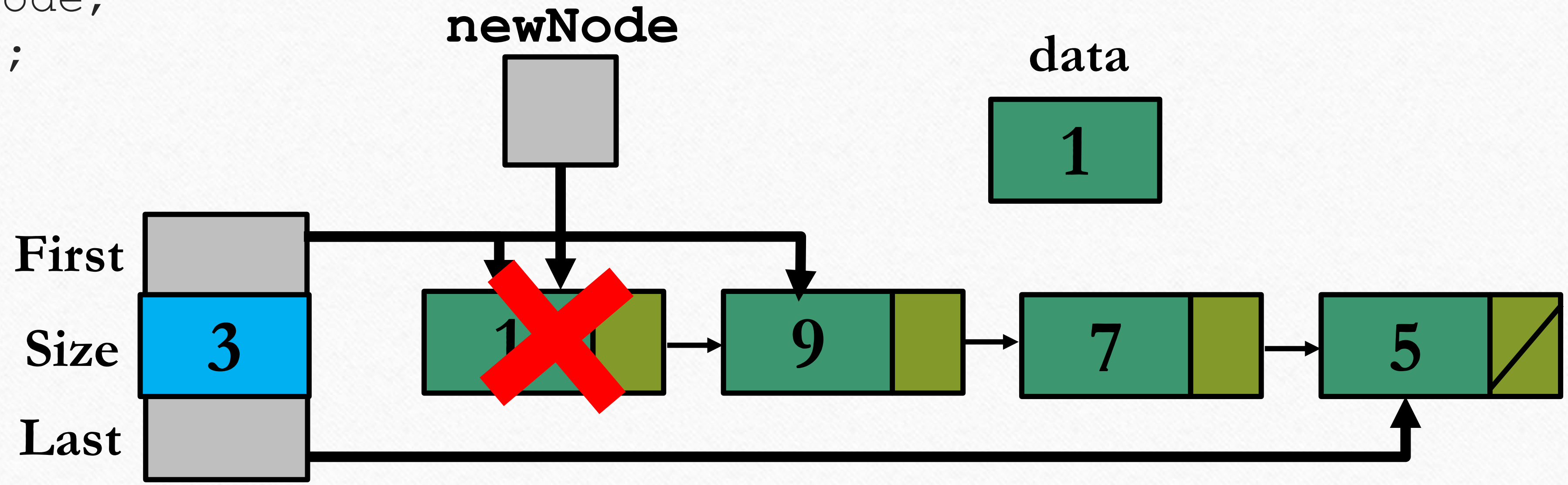




```
int DeQueue(QUEUE &Queue) {
////////////////
if (Queue.first == Queue.last){
    Queue.first = Queue.last = NULL;
 }
 else {
 Queue.first = Queue.first -> next;
}
 Queue.size--;
 delete newNode;
 return data;
}
```



```
int DeQueue(QUEUE &Queue) {
 ////////////////
if (Queue.first == Queue.last){
   Queue.first = Queue.last = NULL;
 }
 else {
 Queue.first = Queue.first -> next;
 }
 Queue.size--;
 delete newNode;
 return data;
}
```

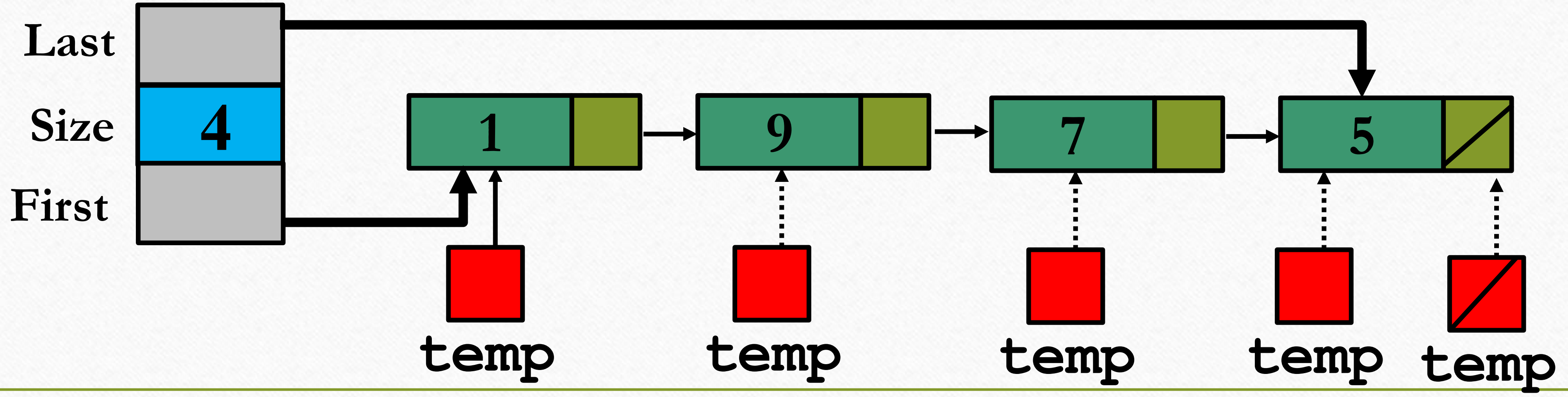


V. Queues (Implementing Queue Operations)

```
// Display all elements of the Queue
void display(QUEUE Queue){
    Node *newNode = Queue.first;
    while(newNode != NULL){
        cout << newNode -> data << "-->";
        newNode = newNode -> next;
    }
    cout << "NULL" << endl;
}
```

```
void display(Queue Queue){
    Node *nowNode =Queue.first;
    while(nowNode != NULL){
        cout << nowNode -> data << "-->";
        nowNode = nowNode -> next;
    }
    cout << "NULL" << endl;
}
```

1--> 9--> 7--> 5--> NULL



V. Queues

Queue Complexity Analysis

Function	Time Complexity	Auxiliary Space Complexity
isEmpty()	$\mathcal{O}(1)$	$\mathcal{O}(1)$
isFull()	$\mathcal{O}(1)$	$\mathcal{O}(1)$
Size()	$\mathcal{O}(1)$	$\mathcal{O}(1)$
EnQueue()	$\mathcal{O}(1)$	$\mathcal{O}(1)$
DeQueue()	$\mathcal{O}(1)$	$\mathcal{O}(1)$
display()	$\mathcal{O}(n)$	$\mathcal{O}(1)$

Questions ?