Chapter 5
LINKED LIST

Data Structure & Algorithm

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Syllabus

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Outlines

- Introduction
- Linked List as an ADT
- Dynamic Implementation
- Insertion & Deletion of Node To and From a List
- Insertion & Deletion of Node After and Before Nodes
- Linked Stacks & Queues
- Doubly Linked Lists & its Advantages

Introduction to Linked List

- Linked List is a collection of nodes where each node consists of at least two parts:

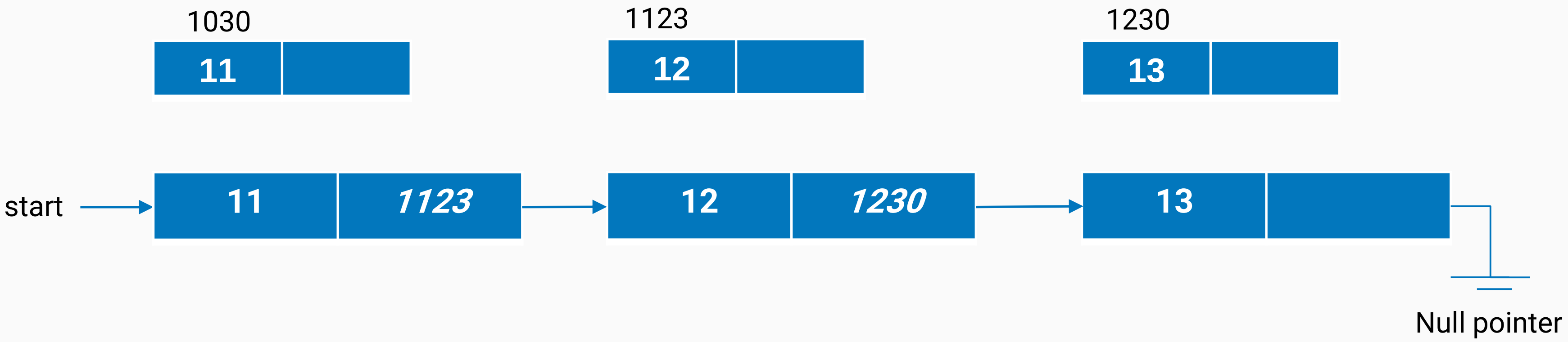
  i. **Information field or info field** : It contains the actual element to be stored.

  ii. **Linked or address field**: It contains one or two links that points to the next node or previous node in the list.

Figure. A node

✓ The memory for nodes of the linked list can be allocated dynamically whenever required.

Introduction to Linked List



Note:

- The first element of the list is known as **head** & the last element is known as **tail**.

Introduction: Basic Operations in Linked List

1. **Insertion:** This operation is creates a new node & inserts it into the list. A new node may be inserted at

- ✓ At the beginning of the list (insert Head)
- ✓ At the end of the List (insert Tail)
- ✓ At the specified position (insert After, insert Before, insert AtNthPos)
- ✓ If the list is empty, the node to be inserted will be the first node.

2. **Deletion** : This operation is deletes a node from the list. A node may be deleted at

- ✓ At the beginning of the list (delete Head)
- ✓ At the end of the List (delete Tail)
- ✓ At the specified position (delete After, delete Before, delete AtNthPos)

Introduction: Basic Operations in Linked List

3. Traversing

- The process is visiting all the nodes of the linked list from one end to the other is called traversing of the list.

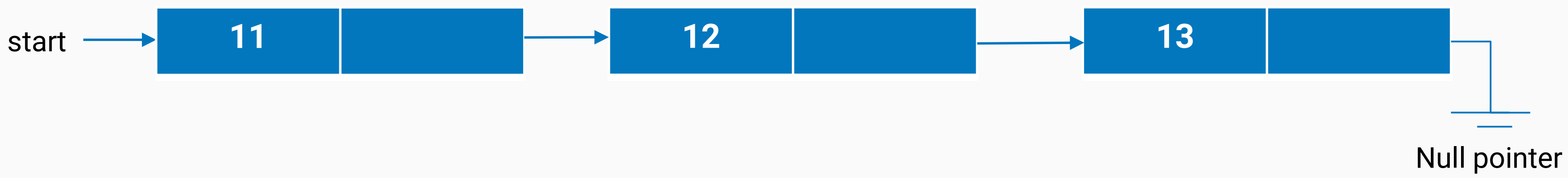
4. Searching:

- This operation checks if a particular data item is present in the list or not.

5. Display:

- This operation is used to print the content of the list.

Null Pointer/ External Pointer/ Empty List



- The linked field of last node contains NULL, rather than a valid address. It is called a **null pointer** & indicates the end of list.

- We use **external pointer or start** which points to the first node of the list. It enables us to access the entire linked list. This pointer must be updated whenever the first node of the list changes.

Null Pointer/ External Pointer/ Empty List

- If no nodes are present in the list, then it is called an **empty list** or a NULL list. The value of external pointer will be assigned NULL for an empty list in our case

*** start = NULL;**

Question : [Explain Linked List as an ADT.]

Values:

✓ A linked list contains a sequence of zero or more nodes.

✓ Each node consists of a general type T and the link field.

✓ It consists of a start pointer and null pointer which indicates start and end of the list respectively.

Linked List as an ADT

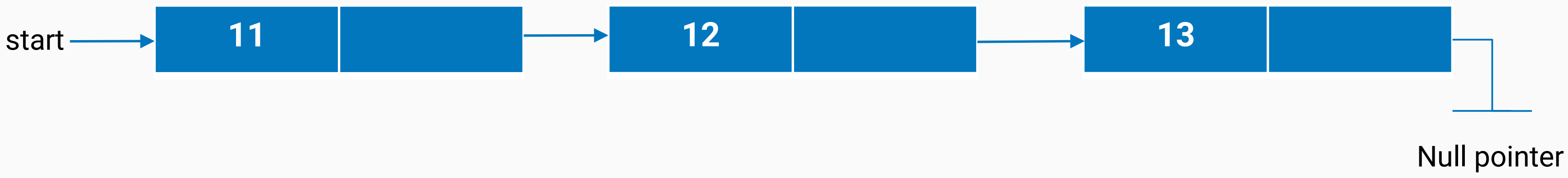
Operations:

i. makeEmpty(L): Make the linked list L an empty list in which start pointer points to the null pointer.
ii. InsertHead(): Insert a new data item at the beginning of the list.
iii. InsertTail(): Insert a new data item at the end of the list.
iv. Insertatposition(): Insert a new data item at the specified position of the list.
v. DeleteHead(): Delete the data item at the beginning of the list.
vi. Deletetail(): Delete the data item at the end of the list.
vii. Deleteatposition(): Delete the data item at the specified position of the list.

Types of Linked List

i. **Singly Linked List or Single Linked List (SLL)**

- It is a linear data structure.
- Only one address field is present in a node. This field stores the address of the following node i.e. it points to the next node.
- The address field of the last node consists of NULL pointer.



Types of Linked List: SLL

Node representation of singly linked list

```
struct node {
        int info;
        struct node * next;
        } ;
```

Here, the type of information stored in ‘int’. Here, next is a pointer to the parent structure type.

Types of Linked List: DLL

ii. **Doubly Linked List (DLL)**

- Two address field are present in a node.
- One of the link stores the address of the following node while the next address field stores the address of the previous node.
- The next link of last node & previous link of first node are NULL

Previous node Address	Info	Next node Address

Types of Linked List: DLL

Node representation of doubly linked list

```
struct node {
        int info;
        struct node * next, * previous;
 } ;
```

Types of Linked List: CLL

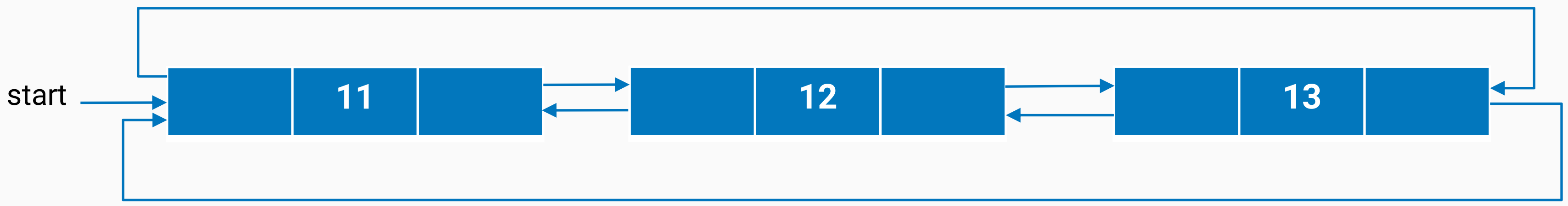
iii. **Circular Linked List (CLL)**

- Only one address field is present in a node. This field stores the address of the following node i.e. it points to the next node.
- The address of the last node consists of the address of the first node. So, the last node will point to the first node.

Types of Linked List: DCLL

iv. **Doubly circular Linked List (DCLL)**

- Two address fields are present in a node. One of the link stores the address of the following node while the next address field stores the address of previous node.
- The next link of last node points to the first node while the previous link of first node points to last node.



Linked list Overview

- The next address field of the last node in the list contains a special value, known as null, which is not a valid address. This null pointer is used to signal the end of a list.
- The list with no nodes on it is called the empty list or the null list.
- The nodes in a linked list are not stored contiguously in the computer’s memory
- We don’t have to shift any element while inserting/deleting in the list
- Memory for each node can be allocated dynamically whenever the need arises
- The no of items in the list is only limited by the computer’s memory

Dynamic Implementation of Linked List

- In Dynamic implementation the size of the structure in not fixed and can be modified during the operations performed on it.
- Linked List is used as a dynamic list.
- A linked list is a data structure is a dynamic structure. It is an ideal technique to store data when the user is not aware of the number of elements to be stored.
- **Linked list** is a series of data items with each item containing a pointer giving a location of next item in the list.

Dynamic Memory Allocation in C

- Dynamic Memory Allocation can be defined as a procedure in which the size of a data structure is changed during the runtime.
- Four library functions that are use in C for dynamic memory allocation are: malloc(), calloc(), free() & realloc(). It is in <stdlib.h> file.
- **malloc():**
    - The name "malloc" stands for memory allocation.
    - **“malloc”** or **“memory allocation”** method in C is used to dynamically allocate a single large block of memory with the specified size.
    - It returns a pointer of type void which can be cast into a pointer of any form. It initializes each block with default ***garbage value***.

Dynamic Memory Allocation in C

- **malloc()**
  - *Syntax* :   **ptr = (cast-type*) malloc(byte-size)**
  - Example: ptr = (int*) malloc(100 * sizeof(int));

  The above statement allocates 400 bytes of memory. It's because the size of float is 4 bytes. And, the pointer ptr holds the address of the first byte in the allocated memory.

- **free()**
  - free method in C is used to dynamically de-allocate the memory
  - It helps to reduce wastage of memory by freeing it.
  - *Syntax:* free(ptr);

Linked List Creation

Linked list can be created as:

```
struct node
{
     int data;
    struct node *next;
};
struct node *;
```
ptr = (struct node *) malloc (sizeof(struct node));

- The struct declaration merely describes the format of the nodes and does not allocate storage.
- Here, the type of the information to be stored is 'int'.
- next is a pointer to the parent structure type. This type of structure is called self-referential structures.
- Storage space for a node is created only when the function malloc() is called in the statement

Algorithm for insertion in singly linked list (SLL)

To insert a node in a list,

- allocate required memory to a node
- assign the data in its information field
- adjust the pointers to link the node at the required place

1. Algorithm for inserting a node at the beginning(head) of the SLL
2. Algorithm for inserting a node at the end(tail) of the SLL
3. Algorithm for inserting a node at the specified position of the SLL

1. Algorithm for inserting a node at the beginning(head) of the SLL

i. Start

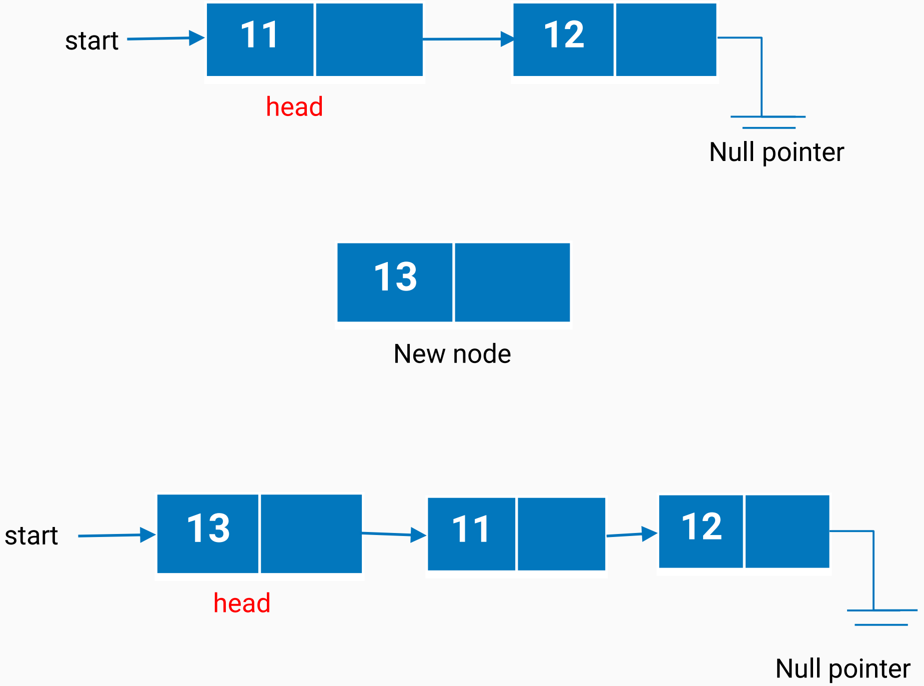
ii. Allocate memory for the new node

iii. Assign value

iv. If the list is currently empty, assign NULL to the link field of the new node. Otherwise, make the link field of the new node to point to the starting node of the linked list.

v. Then, set the external pointer (which is pointing to the starting node) to point to the new node.

vi. Stop

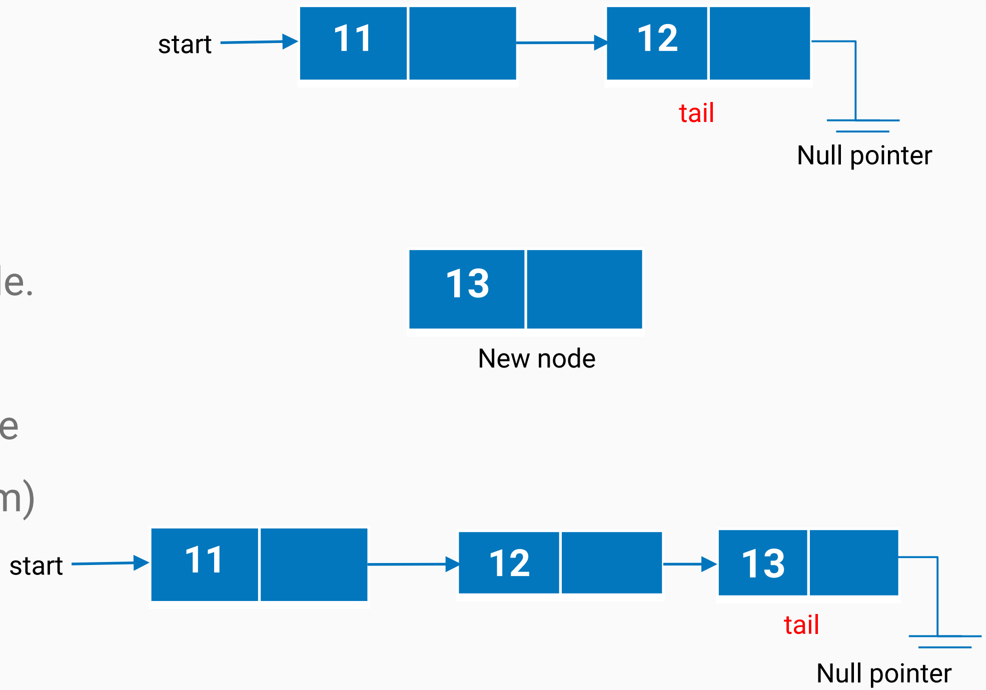


C code for inserting a node at the beginning(head) of the SLL

```
void begin_insert()
{
    struct node *ptr;
    int item;
    ptr = (struct node *) malloc(sizeof(struct node *));
    if(ptr == NULL)
    {
        printf("\nOVERFLOW");
    }
    else
    {
        printf("\nEnter value\n");
        scanf("%d",&item);
        ptr->data = item;
        ptr->next = head;
        head = ptr;
        printf("\nNode inserted");
    }
}
```

2. Algorithm for inserting a node at the end(tail) of the SLL

i. Start
ii. Allocate memory for the new node
iii. Assign value
iv. Assign NULL to the link field of the new node.
v. Traverse the list until last node is reached. Then, insert the new node after the last node by storing the address of the new node (item) to link field of the last node.
vi. Stop



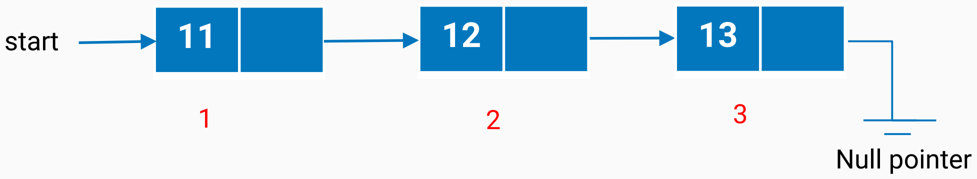
Code for inserting a node at the end(tail) of the SLL

```
void insert_at_the_end()
{
    struct node *ptr,*temp;
    int item;
    ptr = (struct node*)malloc(sizeof(struct node));
    if(ptr == NULL)
    {
        printf("\nLinked List Overflow");
    }
    else
    {
        printf("\nEnter value?\n");
        scanf("%d",&item);
        ptr->data = item;
```

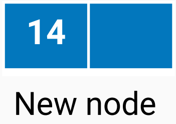
```
if(head == NULL)
        {
            ptr -> next = NULL;
            head = ptr;
            printf("\nNode inserted");
        }
        else
        {
            temp = head;
            while (temp -> next != NULL)
            {
                temp = temp -> next;
            }
            temp->next = ptr;
            ptr->next = NULL;
            printf("\nNode inserted");

        }
    }
}
```

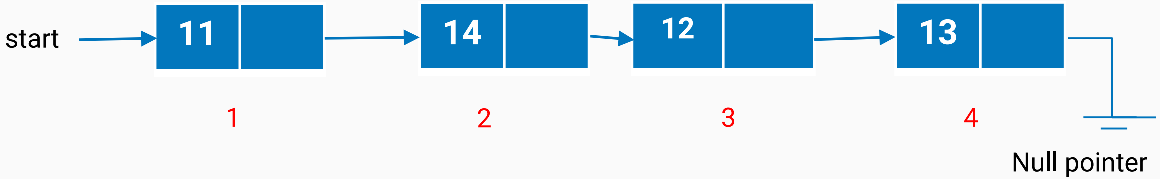
3. Algorithm for inserting a node at the specified position of the SLL

i. Start
ii. Allocate memory for the new node
iii. Assign value
iv. Traverse the list till the given node ***(loc -1).***
v. Assign next of the new node to point link field of **following node**. (e.g. data=12 is the following node)
vi. Assign link field of given node to new node.
vii. Stop



Insert new data = 14 at position 2 of list.





Code for inserting a node at the specified position of the SLL

```
void position_insert()
{
   int i,loc,item;
   struct node *ptr, *temp;
   ptr = (struct node *) malloc (sizeof(struct node));
   if(ptr == NULL)
   {
      printf("\nLinked List OVERFLOW");
   }
   else
   {
      printf("\nEnter element value");
      scanf("%d",&item);
      ptr->data = item;
      printf("\nEnter the location after which you want to insert ");
      scanf("\n%d",&loc);
      temp=head;
```

```
for(i=1;i<loc-1;i++)
   {
      temp = temp->next;
      if(temp == NULL)
      {
         printf("\nCan't insert the value\n");
         return;
      }

   }
   ptr ->next = temp ->next;
   temp ->next = ptr;
   printf("\nNode is inserted");
  }
}
```

Algorithm for delete in singly linked list (SLL)

To delete a node from a list

- Find out the node to be deleted.
- Adjust the pointers
- Free the node to be deleted

1. Algorithm for deleting a node at the beginning(head) of the SLL
2. Algorithm for deleting a node at the end(tail) of the SLL
3. Algorithm for deleting a node at the specified position of the SLL

1. Algorithm for deleting a node at the beginning(head) of the SLL

i. Start

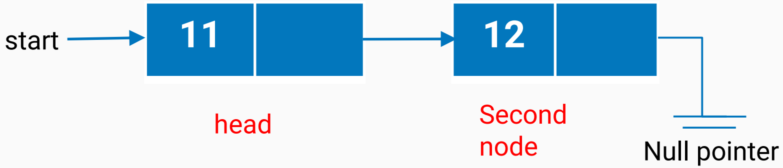
ii. If the list is empty, it is underflow.

Else,

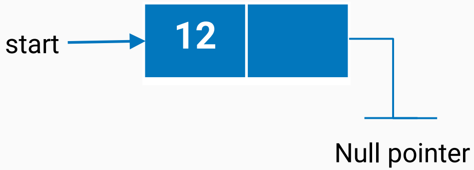
move the start pointer to the second node

iii. Free the first node

iv. Stop



After deletion at the head, the start pointer points to the second node of the Linked List



Code for deleting a node at the beginning(head) of the SLL

```
void begin_delete()
{
    struct node *ptr;
    if(head == NULL)
    {
        printf("\nLinked List is empty\n");
    }
    else
    {
        ptr = head;
        head = ptr->next;
        free(ptr);
        printf("\nNode deleted from the begining ...\n");
    }
}
```

2. Algorithm for deleting a node at the end(tail) of the SLL

i. Start

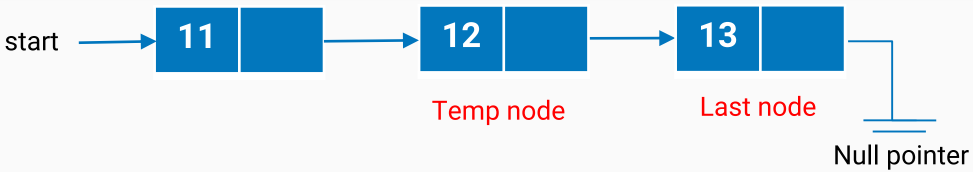
ii. If the list is empty, it is underflow

iii. Else, traverse until the last node is encountered.

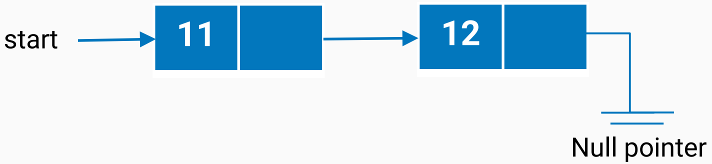
iv. Also keep track of the node, which is before the current node.

v. make the second last node (i.e. temp) to point to NULL and free the last node(i.e. current)

vi. Stop



After deletion of last node, the linked list will be

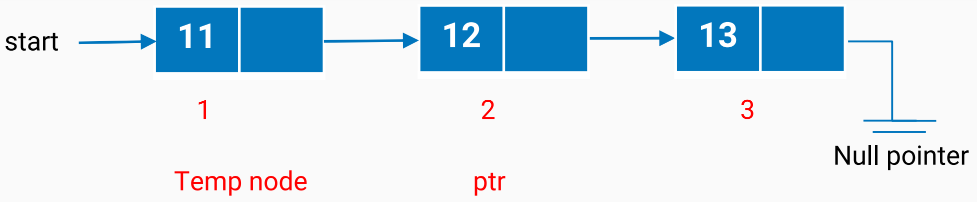


Code for deleting a node at the end(tail) of the SLL

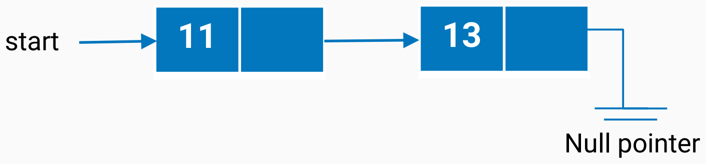
```
void delete_at_the_end()
{
    struct node *ptr,*ptr1;
    if(head == NULL)
    {
        printf("\nlist is empty");
    }
    else if(head -> next == NULL)
    {
        head = NULL;
        free(head);
        printf("\nOnly node of the list deleted ...\n");
    }

    else
    {
     ptr = head;
        while(ptr->next != NULL)
        {
            ptr1 = ptr;
            ptr = ptr ->next;
        }
        ptr1->next = NULL;
        free(ptr);
        printf("\nDeleted Node from the last ...\n");
    }
}
```

3. Algorithm for deleting a node at the specified position of the SLL

i. Start
ii. If the list is empty, it is underflow
iii. Else, traverse until the specified node is encountered (ptr)
iv. Also keep track of the node, which is before the specified node(i.e temp node)
v. make the next of temp to point to next of ptr and free the node pointed by ptr.
vi. Stop



Delete data at position 2 of linked list.



Code for deleting a node at the specified position of the SLL

```
void position_delete()
{
    struct node *ptr,*ptr1;
    int loc,i;
    printf("\n Enter the location of the node after which   you
want to perform deletion \n");
    scanf("%d",&loc);
    ptr=head;
 for(i=0;i<loc;i++)
    {
        ptr1 = ptr;
        ptr = ptr->next;

        if(ptr == NULL)
        {
            printf("\nCan't delete");
            return;
        }
    }
  ptr1 ->next = ptr ->next;
    free(ptr);
    printf("\nDeleted node %d ",loc+1);
}
```

Algorithm for traversing a node in a Linked List

List traversal is the process of visiting all the nodes in the list. Traversal is generally needed to print the items stores in each node of the list.

Step 1: Start

Step 2: If the list is empty, print no element exist.

Step 3: Else, traverse until the temp is not NULL (temp!=NULL)

- While traversing display the info part each time.

Step 4: Stop

Algorithm for searching a node in a Linked List

In order to find an item in a given list, we visit the nodes one after another until we find the item.

Step 1: Start with the first node in the list, as the temp node and keep track of count .

Step 2: Check the info at the current node with the search item

- If the items match, print the value with its position (counter).
- Otherwise, move to the next node and repeat the process

Step 3: If no match is found till we reach the end of the list, print search unsuccessful.

Step 4: Stop

Advantages / Disadvantages of Singly Linked List(SLL)

Pros of SLL

1. Manipulation of a node in a forward direction is easier.
2. Insertion & deletion of node are easier.

Cons of SLL

1. Can insert only after a referenced node
2. Removing node requires pointer to previous node.
3. Can traverse list only in the forward direction

Implementation of Stack using Linked List

- On array implementation of stack the size of the array must be specified at the beginning which might be not feasible in real world scenario.
- For **dynamic implementation** of Stack, **Linked list** can be used.
- There is no need to fix the size at the beginning of this implementation. The no of items in the list is only limited by the computer's memory.

✓ The two operations that we apply on a stack are push (inserting item at the top) and pop (deleting item at the top).

✓ The push operation is similar to adding a new node at the beginning of the linked list (insertHead()).

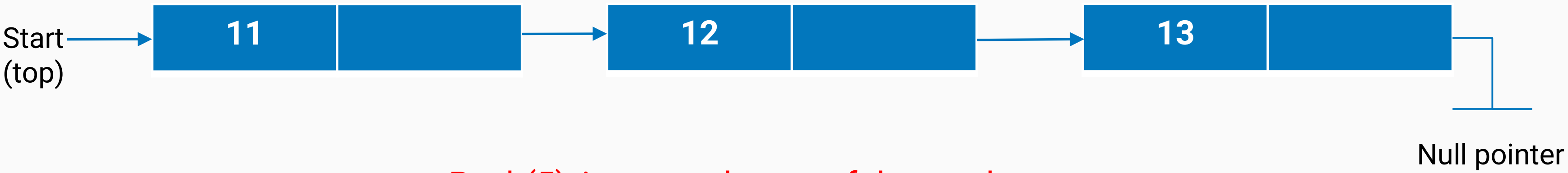
Implementation of Stack using Linked List

- ✓ A stack items can be accessed only through its top, & the list item can be accessed from the start pointer to the first node.
- ✓ Similarly, removing the first node from the linked list (deleteHead()) is similar to popping an item from a stack.

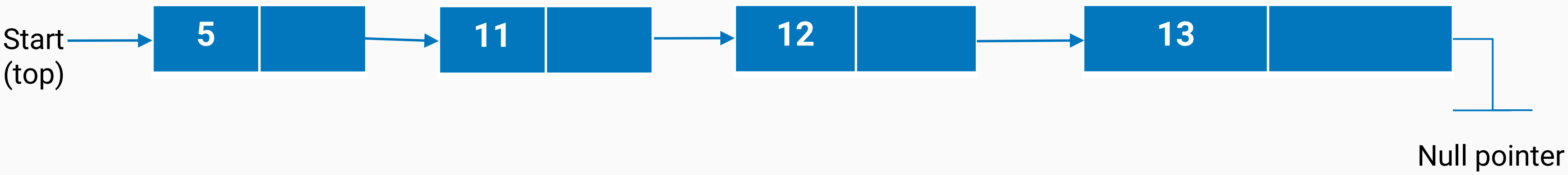
In both cases, the only immediately accessible item of a collection is removed from that collection and the next item becomes immediately accessible one.

- ✓ The first node of the list is top of the stack.

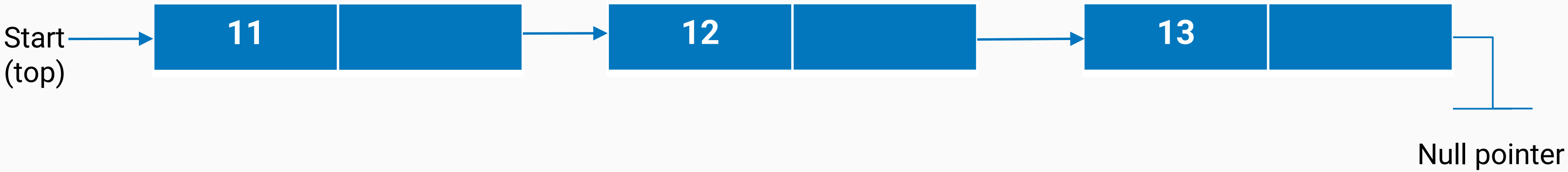
Implementation of Stack using Linked List



Push(5), insert at the top of the stack



Pop(), delete item at the top of the stack



Algorithm for push operation in Stack using Linked List

Step 0 : Start

Step 1 : Create a newNode with given value.

Step 2 : Check whether stack is Empty (top == NULL)

Step 3 : If it is Empty, then set newNode → next = NULL.

Step 4 : If it is Not Empty, then set newNode → next = top.

Step 5 : Finally, set top = newNode.

Step 6 : Stop

Implementation of Stack using Linked List

Algorithm for pop operation in Stack using Linked List

Step 0 : Start

Step 1 : Check whether stack is Empty (top == NULL).

Step 2 : If it is Empty, then display "Stack is Empty!!! Deletion is not possible!!!"
and terminate the function

Step 3 : If it is Not Empty, then define a Node pointer 'temp' and set it to 'top'.

Step 4 : Then set 'top = top → next'.

Step 5 : Finally, delete 'temp'. (free(temp)).

Step 6 : Stop

Implementation of Queue using Linked List

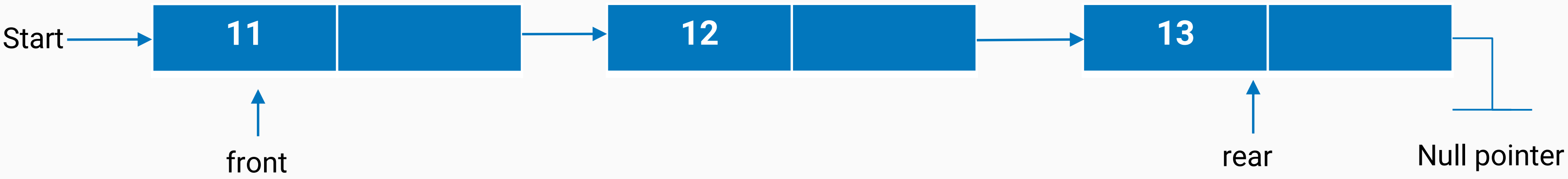
- On array implementation of queue the size of the array must be specified at the beginning which might be not feasible in real world scenario.
- For **dynamic implementation** of Queue, **Linked list** can be used.
- There is no need to fix the size at the beginning of this implementation. The no of items in the list is only limited by the computer's memory.

✓ To implement a queue in a linked list, we make the first node of the linked list as the front & the last node as the rear. So, we will use two pointer variables : front & rear. '**front**' will point to the beginning of the linked list (like start) while '**rear**' will point to the last node of the linked list.

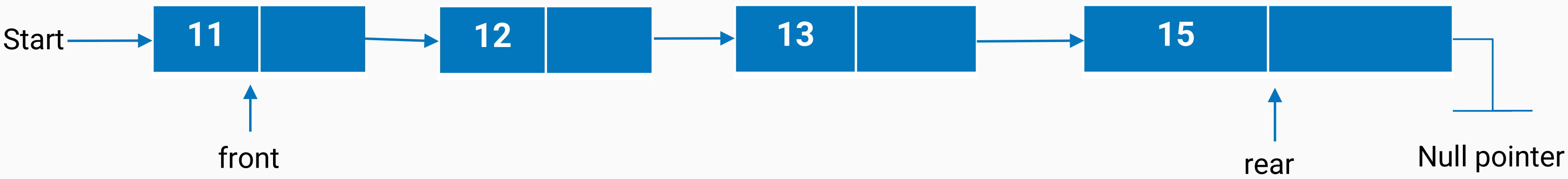
Implementation of Queue using Linked List

- ✓ Initially when the queue is empty, both rear and front will be NULL.
- ✓ To enqueue a new item, we insert it after the rear node & update rear to point to new node. This function will work similarly as (insertTail()), because both are the process to add new item after the last node. In the case of Queue, we insert a new item after the node pointed by ‘rear’.
- ✓ To dequeue an item, we remove the front node and update the front to point to the next node. This function will work similarly as deleteHead() of linked list or pop() operation of stack.

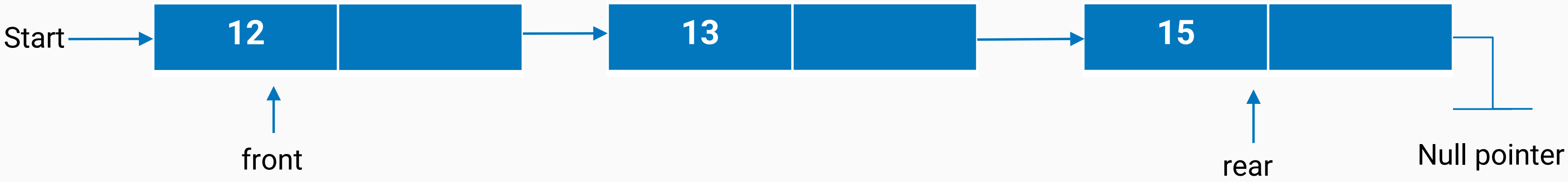
Implementation of Queue using Linked List



Enqueue(15), insert from rear



Dequeue(), delete from front



Implementation of Queue using Linked List

Algorithm for enqueue operation in Queue using Linked List

Step 0 : Start

Step 1 : Create a newNode with given value and set 'newNode → next' to NULL.

Step 2 : Check whether queue is Empty (rear == NULL)

Step 3 : If it is Empty then, set front = newNode and rear = newNode.

Step 4 : If it is Not Empty then, set rear → next = newNode and rear = newNode.

Step 6 : Stop

Implementation of Queue using Linked List

Algorithm for dequeue operation in Queue using Linked List

Step 0 : Start

Step 1 : Check whether queue is Empty (front == NULL).

Step 2 : If it is Empty, then display "Queue is Empty!!! Deletion is not possible!!!" and terminate from the function

Step 3 : If it is Not Empty then, define a Node pointer 'temp' and set it to 'front'.

Step 4 : Then set 'front = front → next' and delete 'temp' (free(temp)).

Step 6 : Stop

Doubly Linked List (DLL)

- Two address field are present in a node.
- One of the link stores the address of the following node while the next address field stores the address of the previous node.
- The next link of last node & previous link of first node are NULL

Previous node Address	Info	Next node Address

- The structure defined for doubly Linked list is:

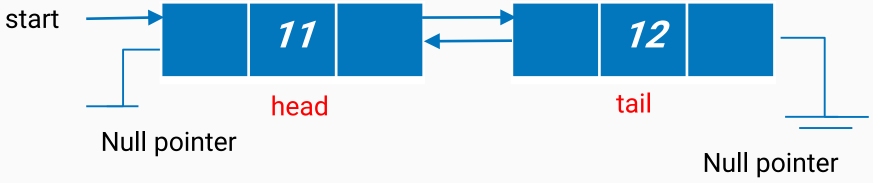
```
struct node {
        int info;
        struct node * next, *prev;
        }
```

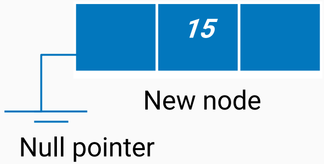
Insertion in DLL

- At the head of linked list
- At the tail of the linked list

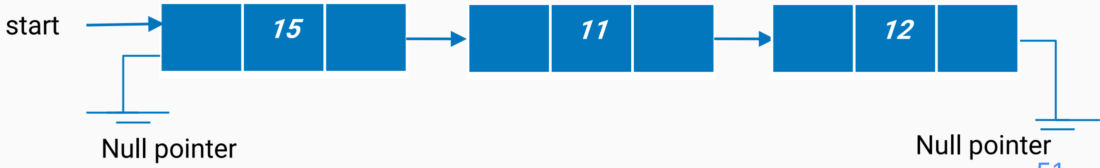
1. Algorithm for inserting a node at the beginning(head) of the DLL

1. Start
2. Allocate memory for the new node.
3. Assign value to the data field of the new node.
4. Assign LEFT link of the new node to NULL.
5. Make the RIGHT link of the new node to point to the head node of the list. And make LEFT link of the head node to point to the new node.
6. Finally reset the head pointer. That is, make it to point to the new node which has inserted at the beginning.
7. Stop



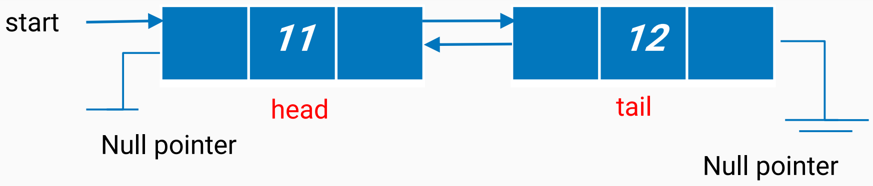


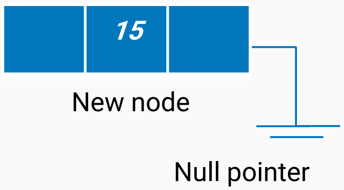
After insertion, we need to adjust the pointers & reset the head node as shown below:



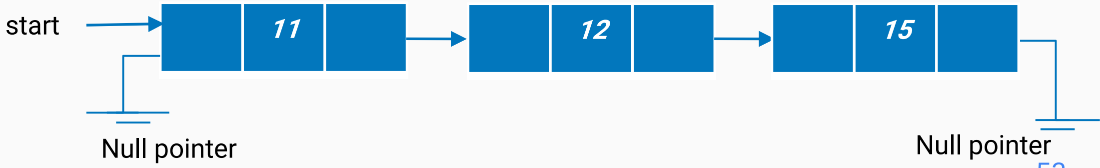
2. Algorithm for inserting a node at the end(tail) of the DLL

1. Start
2. Allocate memory for the new node.
3. Assign value to the data field of the new node.
4. Set the RIGHT links of the new node to point to null.
5. If the list is not empty then traverse the list till the last and make the RIGHT link of the last node to point to the new node & LEFT link of the new node to point to the last node.
6. Stop





After insertion, we need to adjust the pointers as shown below:

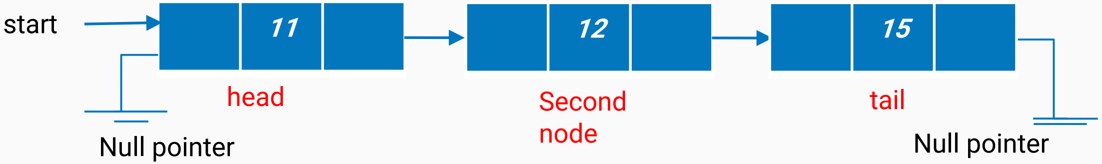


Deletion in DLL

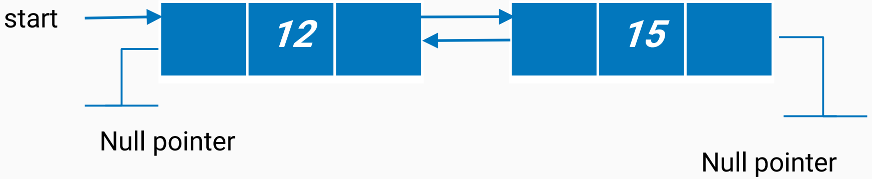
- At the head of linked list
- At the tail of the linked list

1. Algorithm for deleting a node at the beginning(head) of the DLL

1. Start
2. If the list is empty then display the message “ Empty list or No deletion”
3. Otherwise, make the head pointer to point to the second node and if the second node is not null then make its LEFT link of second node to point to NULL. If the second node is NULL then start points to NULL or empty list.
4. Free the first node.
5. Stop



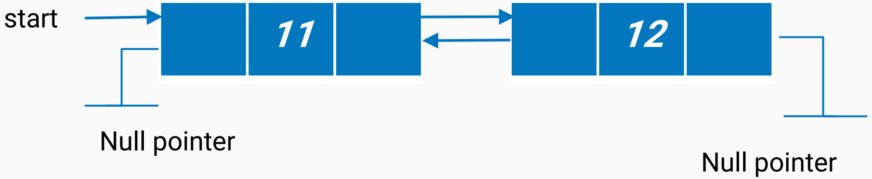
After deletion, we need to adjust the pointers & reset the head node to point to second node as shown below:



2. Algorithm for deleting a node at the end(tail) of the DLL

1. Start
2. If the list is empty then display the message “ Empty list No deletion”
3. Otherwise, traverse the list till the last but one node previous (loc -1) as temp and make the RIGHT link of the temp node to point to NULL. If there is only one node then point start to NULL.
4. Free the last node.
5. Stop

After deletion, we need to adjust the pointers as shown below:



Advantages/ Disadvantages of Doubly Linked List (DLL)

PROS:

1. Insertions & deletions are simple as compared to other linked list.
2. Bi directional (both forward & backward) traversal helps in efficient & easy accessibility of nodes.

Cons

1. Since, it uses two pointers, which results in more memory space requirement.

Question to Focus

1. “List can be represented in memory by using both array & pointer”. Explain this statement.
2. Define linked list. Explain dynamic implementation of list.
3. Explain the algorithm to implement stack using linked list.
4. How can queue be implement using linked list? Write down both its enqueue & dequeue algorithm.
5. How dynamic list is more efficient as compared to static list? List basic five operations of linked list.
6. Define doubly linked list. Write an algorithm to delete at the end of the Doubly linked list (DLL).
7. What are the advantages & disadvantages of linked list? Write an algorithm to insert a node in specified position in single linked list.
8. Write down node representation of DLL. List out pros & cons of SLL & DLL.
9. Explain different types of Linked list in brief.
10. Write down the algorithm for:

i. Insert at the end of the doubly linked list (DLL)

ii. Delete at the beginning of the doubly linked list (DLL)

THANK YOU

Any Queries ?

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