

## Linked List (sequential Data Structure)

### Disadvantages of array

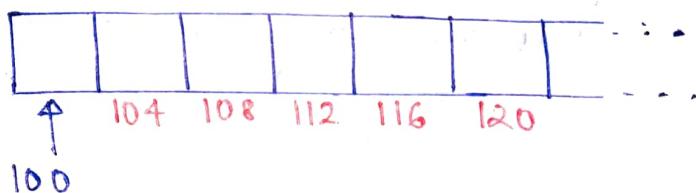
#### \* types of array in C++ :-

- `int arr[100];` → Fixed size
  - `int arr[n];` → user defined size
  - `int *arr = new int[n];`
  - `vector<int> v;` → dynamic arrays
- } allocated on stack frame of function  
→ allocated dynamically on heap

The main problem is we have fixed size for arrays.

Suppose we've an array of size 6.

`int arr[6];`



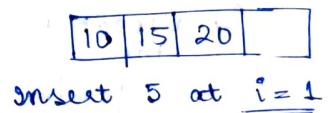
Now if I want to add one more element, we have to insert it at  $(124)^{\text{th}}$  address. But we are not aware whether this position is free or not.

Also in vectors, when the initial size is finished, and we have to add one more element that operation is too costly.

There will be one operation ~~for~~ of complexity  $O(n)$

As the average complexity is  $O(1)$  but <sup>in</sup> the runtime we can't allow any operation to be costly.

- Also the insertion in the middle is costly, deletion too.
- Implementation of Data structures like queue, deque is complex with linked list.



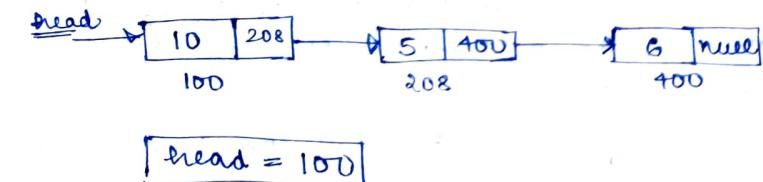
we have to shift all the elements after  $i=0$  to one position ahead.

suppose we've an array of 1000 elements and we have to insert at  $i=2$ , we have to shift the remaining 998 element one step forward.

\* If my memory is fragmented, then it's really difficult to allocate large space using array.

## Introduction

- \* Linear data structure
- \* contiguous memory requirement is dropped.
- \* store pointers of next node.
- \* NO need to pre-allocate space



Every node contains → own data  
→ reference to next node.

data \* P

This type of storage is not achieved by primitive data types

we will create our own data type

This is achieved by classes or structures

Now, what are the requirements

① int data / char data / bool data --- etc

② ~~int~~ \*P address ← address of next node

← \*next

type = node type (Node \*next)

```
class Node {
    int data;
    Node *next;
}
```

\* last node contains NULL to show, that there is no node after that.

\* We can also implement this using structures

```
struct Node {
    int data;
    Node *next;
    Node(int x) {
        data = x;
        next = NULL;
    }
}
```

→ pointer type is same as type of structure  
(self Referencing structure)

→ constructor.

## Implementation

```
int main() {
    Node *head = new Node(20);
    Node *temp1 = new Node(30);
    Node *temp2 = new Node(50);
    head->next = temp1;
    temp1->next = temp2;
    return 0;
}
```

[ 20 | 30 | 50 ]

## Simpler implementation

```
Node *head = new Node(20);
head->next = new Node(30);
head->next->next = new Node(50);
return 0;
```

[ 20 | 30 | 50 ]



Node \*head = new Node(20)  
This will create  
a node having  
value 20  
(syntactically)

## Statically

Node n1(20) - creating object of class Node.  
Node n1(20); Address of n1 is (n1).

## Creating Node statically

```
Node n1(10);
Node *head = &n1;
```

## Traversal of linked list



O/P → 10, 20, 40, 50

void printlist(Node \*head){

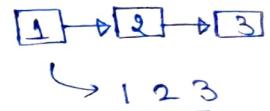
```
Node *curr = head;
while (curr != NULL) {
    cout << curr->data;
    curr = curr->next;
}
```

} we can directly  
use the head  
pointer  
In C++ never  
we pass pointer  
to a function  
it is passed by  
value not  
reference

## Recursive function to print linked list

void print(Node \*head){

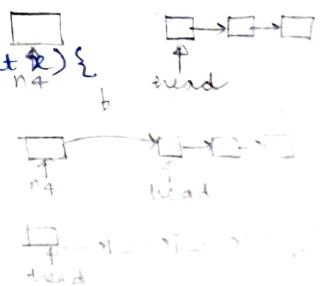
```
if (head == NULL)
    return;
cout << (head->data) << " ";
print(head->next);
}
```



## Insertion of a Node in Linked List

### ① In beginning -

```
Node *insertBegin(Node *head, int x) {
    Node *temp = new Node(x);
    temp->next = head;
    head = temp; } or
    return temp;
```



#### \* Insertion at End

I/P  $\rightarrow$  [10]  $\rightarrow$  [20]  $\rightarrow$  [30], 5  
 O/P  $\rightarrow$  [10]  $\rightarrow$  [20]  $\rightarrow$  [30]  $\rightarrow$  [5]

```
void insertEnd(Node *head, int data) {
    Node *temp = new Node(data);
    temp->next = NULL;
    while (temp->next != NULL) {
        temp = head->next;
    }
    head->next = temp;
```



Node void \*insertEnd (Node \*head, int x) {

```
Node *tmp = new Node(x);
if (head == NULL) {
    return temp;
}
Node *curr = head;
while (curr->next != NULL)
    curr = curr->next;
curr->next = temp;
return head;
```

Traverse upto last node

If head is null, temp becomes head

#### \* Delete First Node of singly linked list:

I/P  $\rightarrow$  [10]  $\rightarrow$  [20]  $\rightarrow$  [30]  
 O/P  $\rightarrow$  [20]  $\rightarrow$  [30]

I/P  $\rightarrow$  [10]  
 O/P  $\rightarrow$  Null

I/P  $\rightarrow$  null  
 O/P  $\rightarrow$  null.



Node \*DeleteBegin (Node \*head) {

```
if (head == NULL)
    return NULL;
Node *temp = head;
temp = temp->next;
delete (temp);
```

return temp;

deleting memory space  
deallocating

#### ① Delete Last Node of linked list

Node \*delLast (Node \*head) {

```
if (head == NULL) {
    return NULL;
}
```

```
if (head->next == NULL) {
    delete (head);
    return NULL;
}
```

Node \*tmp = head;

```
while (tmp->next != NULL) {
    tmp = tmp->next;
}
```

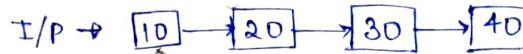
```
Node *curr = tmp->next;
delete (curr);
temp->next = NULL;
return head;
```

while (tmp->next->next != NULL)  
 tmp = tmp->next

Ensuring atleast two nodes are present

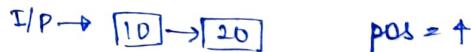
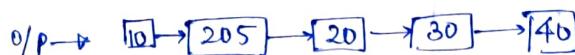
$\Theta(n)$

#### \* insert at given position in singly linked list



pos = 2

data = 205



- We have to run a loop ( $pos-2$ ) times as we want the previous node to link.
- We also want that  $curr \neq \text{NULL}$ .

```
Node * insertPos ( Node *head, int pos, int data) {  
    Node *temp = new Node(data);  
    if (pos == 1) {  
        temp->next = head;  
        return temp;  
    }  
    for (int i = 0; i < pos-2 && curr != NULL; i++)  
        curr->next;  
    if (curr == NULL) {  
        delete (temp);  
        return head;  
    }  
    temp->next = curr->next;  
    curr->next = temp;  
    return head;  
}
```

#### Search in a linked list



O/P  $\rightarrow$  3

int search (Node \*head, int x) {

```
    int pos = 1;  
    Node *curr = head;  
    while (curr != NULL) {  
        if (curr->data == x)  
            return pos;  
        else {  
            pos++;  
            curr = curr->next;  
        }  
    }  
    return -1;  
}
```

$O(1) \rightarrow \text{Aux space}$

#### Recursive solution

$O(n)$

int search (Node \*head, int x) {

```
    if (head == NULL)  
        return -1;
```

```
    if (head->data == x)  
        return 1;
```

```
    int res = search (head->next, x);
```

```
    if (res == -1) return -1;
```

```
    return res + 1
```

## Taking Input as linked list

- we assume that when user enters -1, we have to terminate our linked list or we doesn't want to continue.

\* If we allocate node statically.

```
For ex:- while (data != -1) {  
    Node n(data);  
}
```

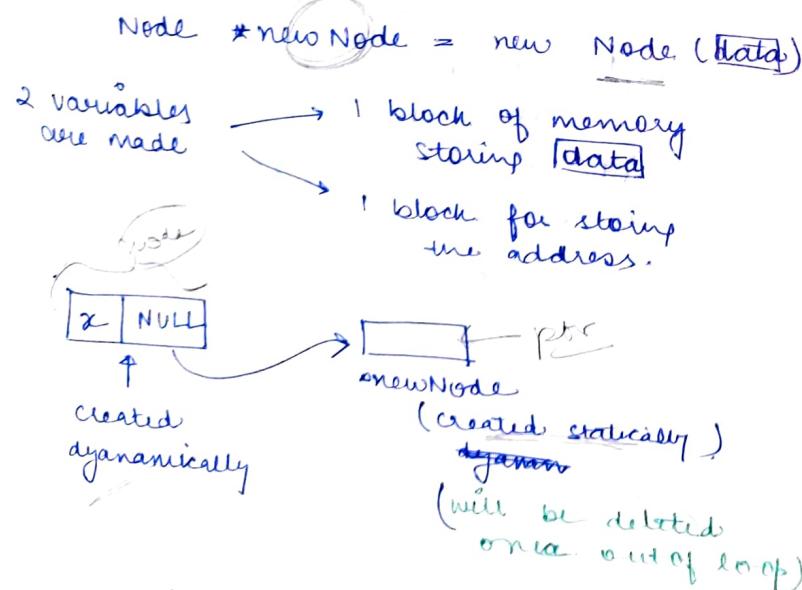
Now the scope of n is ~~what~~ within the while loop only, even if the loop runs the previous allocated node is deleted.

To prevent this we use dynamic allocation, the allocated node will not be deallocated unless the programmer itself deletes that.

```
Node *newNode = new Node(data);
```

\* we have to store the address of head node.

In this line



## Node \*takeinput()

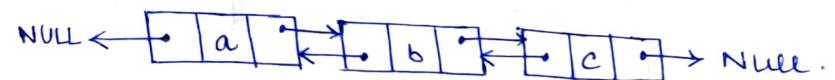
```
int data;  
cin >> data;  
Node *head = NULL;  
Node *prev = NULL;  
while (data != -1) {  
    Node *created = new Node(data);  
    if (head == NULL) {  
        head = created;  
    }  
    else {  
        prev->next = created;  
    }  
    prev = created;  
    cin >> data;  
}  
return head;
```

[O(n)]

## DOUBLY LINKED LIST

Has two pointers

→ pointing to next node  
→ pointing to previous node



```
struct Node {
```

```
    int data;  
    Node *prev;  
    Node *next;  
    Node (int d) {  
        data = d;  
        prev = NULL; next = NULL;
```

Structure for  
doubly linked  
list

## Implementation to create a doubly linked list

```

int main(){
    Node *head = new Node(10);
    Node *n1 = new Node(20);
    Node *n2 = new Node(30);

    head->prev = NULL;
    head->next = n1;
    n1->prev = head;
    n1->next = n2;
    n2->prev = n1;
    n2->next = NULL;
}
  
```

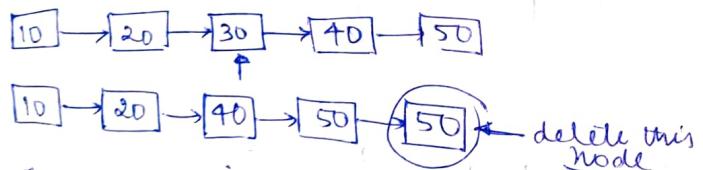


• Not needed as already declared in constructor.

## Singly vs Doubly linked lists

### Advantages

- Can be traversed in both directions
- A given node can be deleted in O(1) time  
(In singly linked list, this is not possible, the only solution is:



But this is not possible when the given node is tail of linked list.

- ① Insert/delete before the given node.
- ② Insert/delete at the end in O(1) time.

### Disadvantages

- ① Extra space for prev
- ② code becomes complex.

## Insert data at the beginning of linked list

I/P →  $x = 30$   
O/P →

I/P → NULL, 30  
O/P →

Node \*insertBegin (Node \*head) int x) {

Node \*temp = new Node(x);

if (head == NULL)

return temp;

temp->next = head;

head->prev = temp;

return temp;

}

• temp becomes the new head

## Insert at the End of linked list

I/P →  $x = 30$   
O/P →

Node \*insertEnd (Node \*head, int x) {

Node \*temp = new Node(x);

if (head == NULL)

return temp;

Node \*curr = head;

while (curr->next != NULL) {

curr->next;

curr->next = temp;

temp->prev = curr;

return head;

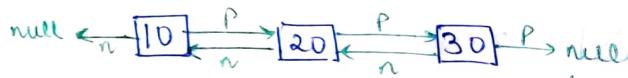
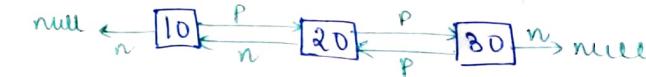
## Reverse a Doubly Linked List

I/P  $\rightarrow$  [10]  $\rightarrow$  [20]  $\rightarrow$  [30]

O/P  $\rightarrow$  [30]  $\leftarrow$  [20]  $\leftarrow$  [10]

- we need to swap the prev and next pointer of every node.

Ex:-



(Reversed)

### Node \* reverseLL (Node \* head) {

```
if (node == NULL || node->next == NULL)
    return head;
```

while (true)

Node \* curr = head, \*temp = NULL;

while (curr != NULL) {

```
temp = curr->next;
curr->next = curr->prev;
curr->prev = temp;
curr = curr->prev;
```

} swapping

```
return curr->prev;
```

## Delete head node of Doubly linked list

I/P  $\rightarrow$  [10]  $\rightarrow$  [20]  $\rightarrow$  [30]

O/P  $\rightarrow$  [20]  $\rightarrow$  [30]

Node \* deleteHead (Node \* head) {

if (head == NULL)

return NULL;

if (head->next == NULL) {

delete (head);

return NULL;

}

Node \* curr = head;

curr = curr->next;

curr->prev = NULL;

head->next = NULL; \* not required

delete (head);

return curr;

## Delete Tail of Doubly linked list

Node \* deleteTail (Node \* head) {

if (head == NULL)

return NULL;

if (head->next == NULL) {

delete (head);

return NULL;

}

Node \* curr = head;

while (curr->next->next != NULL) {

curr = curr->next;

}

delete (curr->next);

curr->next = NULL;

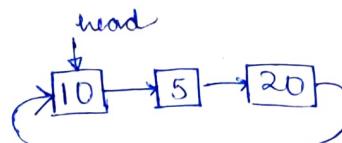
return head;

4

## Circular linked list

tail's next is linked back to head

single node linked list →



head → next = head.

### advantages

- we can traverse the whole list from any node
- implementation of algorithm like round robin
- we can insert at beginning / end by maintaining one tail pointer.

### Traversal of circular LL

#### method-1

```

void print (head) {
    if (head == NULL)
        return;
    Node *p = head;
    do {
        cout << p->data;
        p = p->next;
    } while (p != head);
}
  
```

#### insert in the beginning

I/P →      x=5

O/P →      ↗ 10

I/P → NULL      x=10      O/P ↗ 10

#### 1<sup>st</sup> Method

```

Node * insertBegin (Node * head, int x) {
    Node *temp = new Node (x);
    if (head == NULL) {
        temp->next = temp;
    }
    else {
        Node *curr = head;
        while (curr->next != head)
            curr = curr->next;
        curr->next = temp;
        temp->next = head;
    }
    return temp;
}
  
```

} For updating the tail link

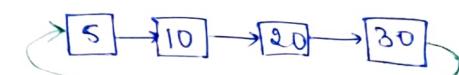
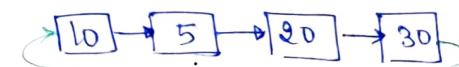
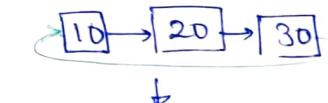
#### 2<sup>nd</sup> Method O(1) time

we can maintain a tail pointer and then every operation is done in O(1)-time

OR.

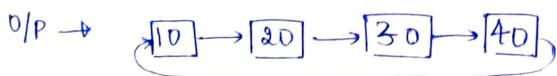
we can insert a node after head and then swap the values of head & head→next

x=5 ,



swapping the values only

## Insert at the end of Circular linked list



### Method-1

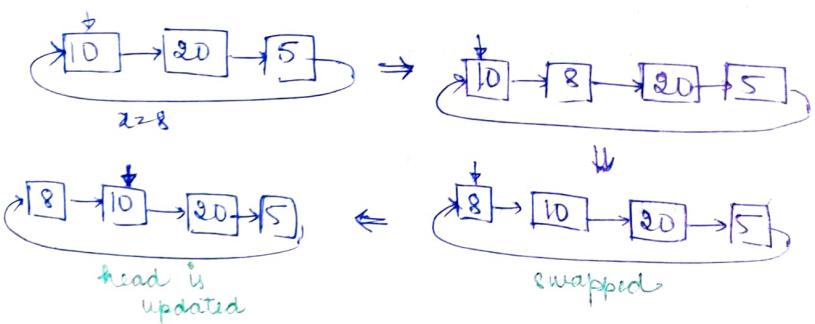
just traverse to the tail of linked list and add the new node.

### Method-2

Maintain a tail pointer

### Method-3

- insert a node after head
- swap the data of new node and head
- shift the head pointer to the new node.



```

temp->next = head->next;
head->next = temp;
int t = temp->data;
temp->data = head->data;
head->data = t
return temp;
  
```

New head

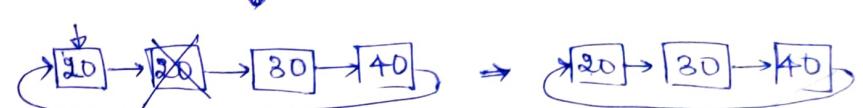
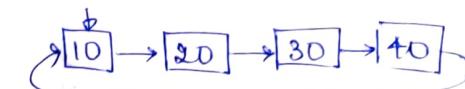
## Delete the head of CLL

### Method-1

loop through the list linked list and move to the tail and delete the head node

### Method-2

copy the content of 'head->next' to 'head' node & and then delete the head node



## Delete k<sup>th</sup> Node in linked list

I/P →  k=2.

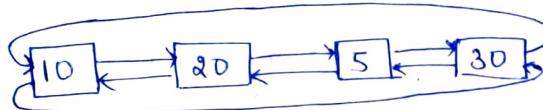
O/P → 

no of node ≥ k

```

Node * deleteKth (Node * head, int k) {
    if (head == NULL) return head;
    if (k == 1) return deleteHead (head);
    Node * curr = head;
    for (int i=0 ; i < k-2 ; i++)
        curr = curr->next;
    Node * temp = curr->next;
    curr->next = curr->next->next->next;
    delete temp;
    return head;
}
  
```

## Circular linked list



having only one node +



## Advantages

- All the advantages of circular & doubly LL.
- we can get tail pointer in O(1) operation.

## Insert in CDLL (head)

```

Node * temp = new Node(x);
if (head == NULL) {
    temp->next = temp;
    temp->prev = temp;
    return temp;
}
  
```

```

temp->prev = head->prev;
temp->next = head;
head->prev->next = temp;
head->prev = temp;
return temp;
  
```

- Insert at the end has exactly the same code. we just need to return head only, which means that we don't need to change head.

return temp ✕  
return head ✓.

## Sorted insert in the linked list

I/P → 10 → 20 → 30 → 40      x = 35  
O/P → 10 → 20 → 30 → 35 → 40

```

Node * sorted_Insert (Node * head, int x) {
    Node * temp = new Node(x);
    if (head == NULL)
        return temp;
    if (x < head->data) {
        temp->next = head;
        return temp;
    }
    Node * curr = head;
    while (curr->next = NULL && curr->next->data < x) {
        curr = curr->next;
    }
    temp->next = curr->next;
    curr->next = temp;
    return head;
}
  
```

} insert before head.  
} updating the position  
} insert the temp

## MID Element of a linked list

There are two possible questions

- ① even length

① → ② → ③ → ④ → ⑤ → ⑥ → null  
mid element → 3, 4

- ② odd length

① → ② → ③ → ④ → ⑤ → null

mid → 3

### Method-1

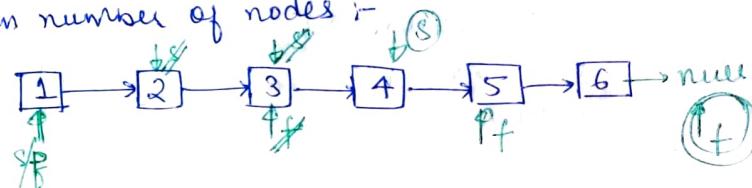
calculate length of linked list and just do  $\text{len}/2$

- If we want the first node in even length linked list, we can calculate pos =  $\left(\frac{\text{len}-1}{2}\right)$ .

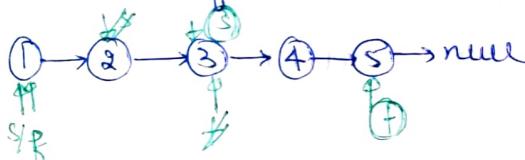
### Method-2

- declare 2 pointers → slow (moves 1 pos ahead)  
→ fast (moves 2 pos ahead)

For even number of nodes :-



For odd number of nodes :-



condition → fast != NULL &&  
fast->next != NULL.

```

void printMiddle(Node *head){
    if(head == NULL) return;
    if
        Node *slow = head, *fast = head;
        while(fast != NULL && fast->next != NULL){
            slow = slow->next;
            fast = fast->next->next;
        }
    cout << slow->data;
}
  
```

y

### N<sup>th</sup> Node from End of linked list

I/P → [10] → [20] → [30] → [40] → [50] n=2

O/P → 40

I/P → [10] → [20] n=3

O/P → —

### Method-1

If we calculate length, then the nth node from end will be the  $(\text{len}-n+1)^{\text{th}}$  node from beginning.

calculating length → for (Node \*curr = head; curr != NULL; len++)  
curr = curr->next;

Now  
checking

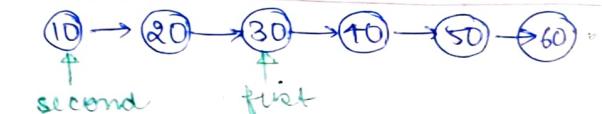
if (len < n){  
return;

printing the  
node

Node \*curr = head  
for (int i = 1; i < len-n+1; i++)  
curr = curr->next  
cout << curr->data;

### Method-2

M=2



- Move first pointer n positions ahead.
- Maintain a pointer named second starting from head
- we now move first & second pointer at same speed
- stop when first reaches null, second pointer reaches at required position

```

.id printNthNode (Node* head, int n) {
    if (head == NULL) return;
    Node *first = head;
    for (int i=0; i<n; i++) {
        if (first == NULL) return;
        first = first->next;
    }
    Node *second = head;
    while (first != NULL) {
        second = second->next;
        first = first->next;
    }
    cout << second->data;
}

```

### Reverse a linked list

I/P  $\rightarrow$  [10]  $\rightarrow$  [20]  $\rightarrow$  [30]      O/P  $\rightarrow$  [30]  $\rightarrow$  [20]  $\rightarrow$  [10]

### Naive Solution

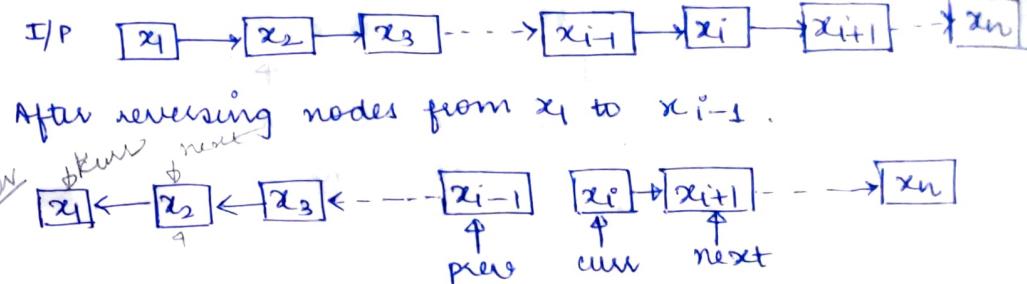
Copy the contents of linked list into a vector and then create a linked list in reverse order.

```

Node *revList (Node *head) {
    for (Node *curr = head; curr != NULL;
         curr = curr->next) {
        arr.push_back(curr->data);
    }
    for (Node *curr = head; curr != NULL;
         curr = curr->next) {
        curr->data = arr.back();
        arr.pop_back();
    }
    return head;
}

```

### Efficient solution



- keep track of prev to link curr  $\rightarrow$  next
- store next so that we don't lose the remaining linked list

### Node \*reverse (Node \*head)

```

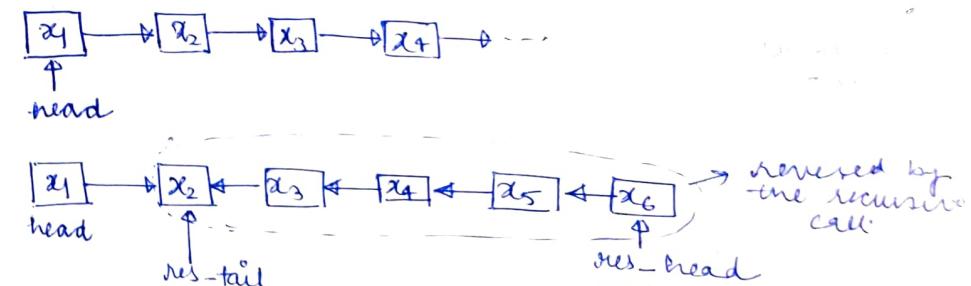
Node *reverse (Node *head) {
    Node *curr = head;
    Node *prev = NULL;
    while (curr != NULL) {
        Node *next = curr->next;
        curr->next = prev;
        prev = curr;
        curr = next;
    }
    return prev;
}

```

$\text{next} = \text{curr} \rightarrow \text{next}$   
 $\text{curr} \rightarrow \text{next} = \text{prev}$   
 $\text{prev} = \text{curr};$   
 $\text{curr} = \text{next};$

$O(n)$

### Reverse a linked list

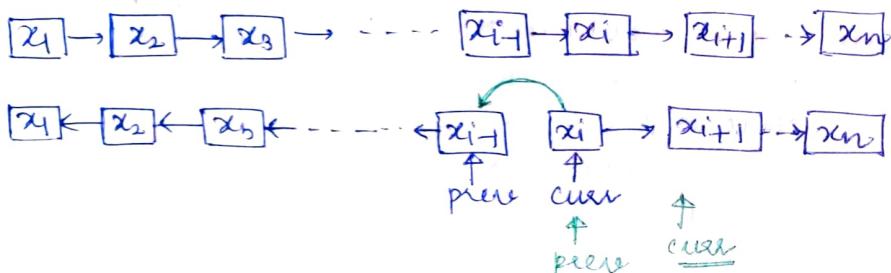


```
node * recRev (Node * head) {
```

```
    if (head == NULL || head->next == NULL)  
        return head;  
  
    Node * new_head = recRev (head->next);  
    Node * new_tail = head->next;  
    new_tail->next = head;  
    head->next = NULL;  
    return new_head;
```

y

### Method-2 (Recursive)



```
Node * recRev (Node * curr, Node * prev) {
```

```
    if (curr == NULL) return prev;  
  
    Node * next = curr->next;  
    curr->next = prev;  
    return recRev (next, curr);
```

y.

- we just update the link and call the next (leftover) list where we update the link and call the leftover ...

### Remove Duplicates from sorted Linked list

I/P  $\rightarrow$  10  $\rightarrow$  10  $\rightarrow$  20  $\rightarrow$  20  $\rightarrow$  20  $\rightarrow$  30  $\rightarrow$  NULL

O/P  $\rightarrow$  10  $\rightarrow$  20  $\rightarrow$  30  $\rightarrow$  NULL

```
void RemoveDup (Node * head) {
```

```
    Node * curr = head;  
    while (curr != NULL && curr->next != NULL) {  
        if (curr->data == curr->next->data) {  
            Node * temp = curr->next;  
            curr->next = curr->next->next;  
            delete (temp);  
        }  
        else  
            curr = curr->next;  
    }
```

### Reverse linked list in groups of size 'k'

I/P  $\rightarrow$  10  $\rightarrow$  20  $\rightarrow$  30  $\rightarrow$  40  $\rightarrow$  50  $\rightarrow$  60 k=3

O/P  $\rightarrow$  30  $\rightarrow$  20  $\rightarrow$  10  $\rightarrow$  60  $\rightarrow$  50  $\rightarrow$  40

I/P  $\rightarrow$  10  $\rightarrow$  20  $\rightarrow$  30  $\rightarrow$  40  $\rightarrow$  50 k=3

O/P  $\rightarrow$  30  $\rightarrow$  20  $\rightarrow$  10  $\rightarrow$  50  $\rightarrow$  40

I/P  $\rightarrow$  10  $\rightarrow$  20  $\rightarrow$  30 R=4

O/P  $\rightarrow$  30  $\rightarrow$  20  $\rightarrow$  10

- If  $k >$  remaining number of nodes, then reverse the remaining



- we reverse the first  $k$  nodes iteratively.
- and then call for reversing the next  $k$ .
- we have to connect the tail of previous reversed linked list to the new head.
- On recursive call we return the new\_head to next reversed list and we store the tail of our list in the calling function.
- we then update the links.

`Node *reversek( Node *head, int k);`

```

Node *curr = head;
Node *next = NULL, prev = NULL;
int count = 0;
while (curr != NULL && count < k) {
    next = curr->next;
    curr->next = prev;
    prev = curr;
    curr = next;
    count++;
}

```

Reverse  
LL in  
groups of  
' $k$ '

```

if (next != NULL) {
    Node res_head = reversek (next, k);
    head->next = res_head;
}
return prev;

```



$\boxed{O(n)}$

Auxiliary space  $\rightarrow O(n/k)$

## Iterative solution to reduce complexity (Space) $O(1)$

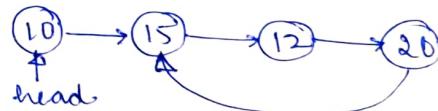
`Node *reversek( Node *head, int k);`

```

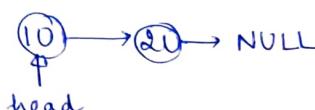
Node *curr = head;
/* prevFirst = NULL;
bool isFirstPass = true;
while (curr != NULL && count < k) {
    Node *first = curr->prev = NULL;
    * count = 0;
    while (curr != NULL && count < k) {
        Node *next = curr->next;
        curr->next = prev;
        prev = curr;
        curr = next;
        count++;
    }
    if (isFirstPass) {
        head = prev;
        isFirstPass = false;
    } else {
        prevFirst->next = prev;
        prevFirst = first;
    }
    return head;
}

```

## DETECT LOOP IN LINKED LIST

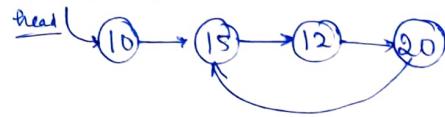
I/P  $\rightarrow$   O/P  $\rightarrow$  Yes.

Or I/P  $\rightarrow$  head = NULL O/P = No

I/P  $\rightarrow$   O/P = No

## Name Solution

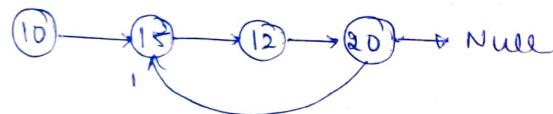
At any  $\ast$  node, run the loop from head to that node to check if next of curr is same as any of previous node.



→ at  $curr \rightarrow data = 15$   
run loop from 10 to 15

→ at 20, run a loop from 10 to 15,  $20 \rightarrow next = 15$

## Method-2 (modification in linked list structure is allowed),



## Structure of linked list

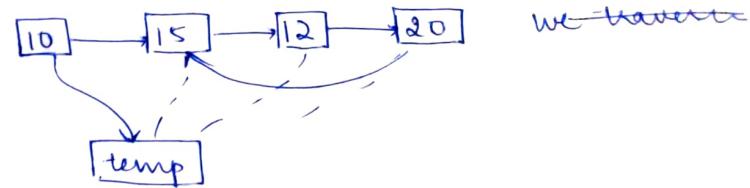
```

struct Node{
    int data;
    Node *next;
    bool visited;
    Node(int data){
        data = data;
        next = NULL;
        visited = false;
    }
}
  
```

- we mark the node visited whenever we visited it
- whenever we see a node already visited, we detect a loop

## (Method-3) Modification to linked list pointer

I/P



we traverse

we traverse the linked list and at every node we change the next of it to temp.. whenever whenever we reach a node whose next is already pointing to temp , we detect a loop. we stop, when  $curr \rightarrow next = \text{NULL}$

### Algorithm :-

```

bool No iLoop (Node *head) {
    Node *temp = new Node;
    Node *curr = head;
    while (curr != NULL) {
        if (curr->next == NULL) return false;
        if (curr->next == temp) return true;
        Node *curr_next = curr->next;
        curr->next = temp;
        curr = curr_next;
    }
    return false;
}
  
```

## Method-4 (Using Hashing)

```

bool iLoop (Node *head) {
    unordered_set<Node *> s;
    for (Node *curr = head; curr != NULL; curr = curr->next)
        if (s.find(curr) != s.end()) return true;
        s.insert(curr);
    return false;
}
  
```

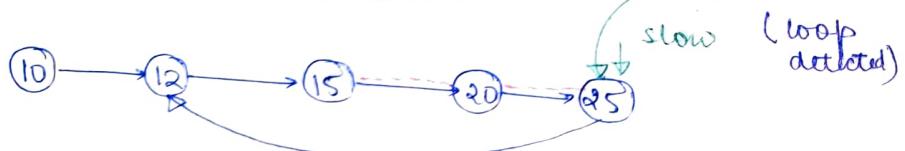
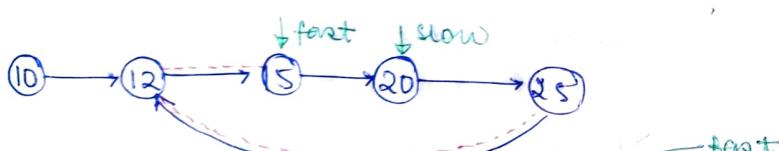
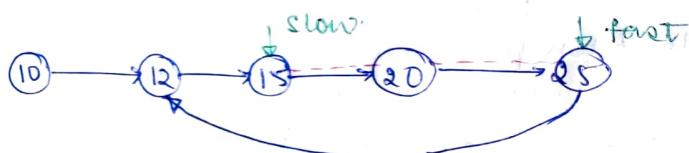
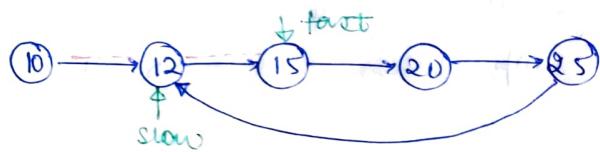
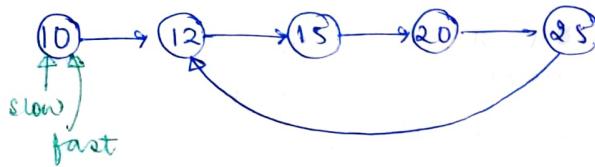
$O(n)$  time

$O(n)$  Aux space

## Detect Loop (Floyd's cycle Detection)

(Hare & Tortoise  
Algorithm)

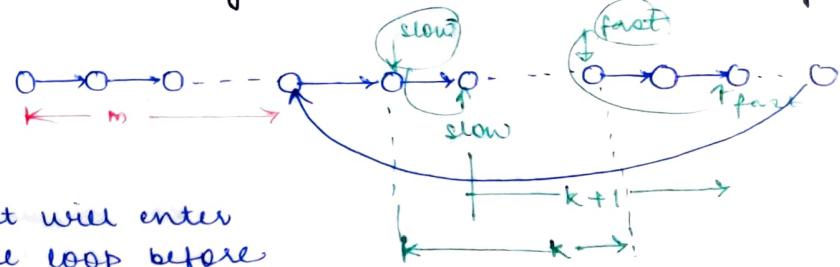
- There is a slow and fast pointer running one & two steps at a time respectively



```
bool isLoop(Node *head);
```

```
Node *slow = head, *fast = head;
while (fast != NULL && fast->next != NULL) {
    slow = slow->next;
    fast = fast->next->next;
    if (slow == fast) return true;
}
return false;
```

## How does the algorithm work (Mathematically).



- fast will enter the loop before slow
- on every iteration the distance b/w them is increased by 1.
- After some iteration there may be a case when distance becomes  $n \rightarrow$  linked list length.  
they are at the same node

Time complexity  $\rightarrow O(m+n)$

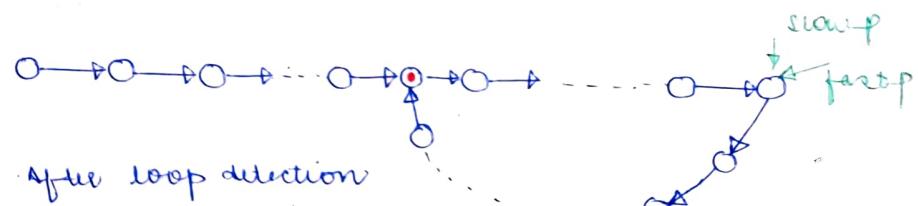
$\rightarrow O(\text{length})$

$m \rightarrow n \rightarrow$  length of loop

of linked list

## Detect and Remove the loop

I/P  $\rightarrow$  10  $\rightarrow$  20  $\rightarrow$  30  $\rightarrow$  40  $\rightarrow$  10  $\rightarrow$  10  $\rightarrow$  20  $\rightarrow$  30  $\rightarrow$  40



- move slow to beginning

move slow to beginning  
And move both slow and fast pointers by 1 position ahead

- The claim is they both will meet at the starting of loop (red node)

```

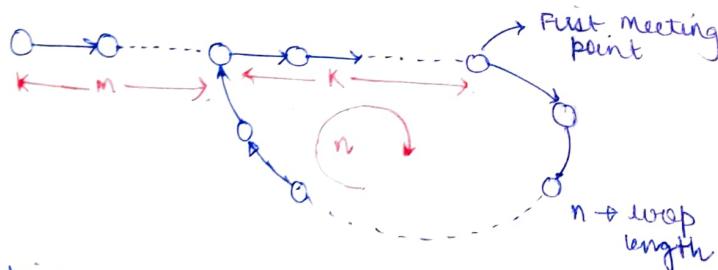
void detectLoop (Node *head) {
    Node *slow = head, *fast = head;
    while (fast != NULL & fast->next != NULL) {
        slow = slow->next;
        fast = fast->next->next;
        if (slow == fast)
            break;
    }
    if (slow != fast)
        return;
    slow = head;
    while (slow->next != fast->next) {
        slow = slow->next;
        fast = fast->next;
        fast->next = NULL;
    }
}

```

**Loop detection**

**Loop removal**

How this algorithm work?



Before first meeting point

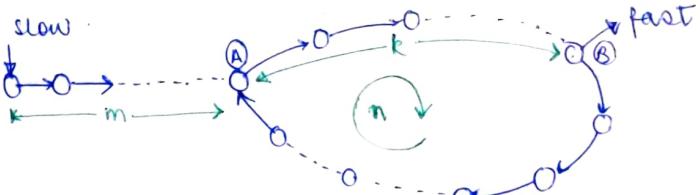
Distance travelled by slow \* 2 = Distance travelled by fast

$$(m+k+2*x)*2 = (m+k+y*n)$$

$$(m+k) = n(y - 2x)$$

$m+k$  is multiple of  $n$ .

$x \rightarrow$  no. of cycles  
slow moves  
before first meeting pt



- \* slow will have to travel  $m$  distance to reach A.
- \* fast will travel ' $n$ ' or  $(m+k)$  to reach at same position i.e. B.
- \* To reach B, fast has to travel ' $k$ ' steps less. (A-B)  
 $m+k-k = m$  steps
- \* ie at  $m$  steps slow and fast both will reach A, their second meeting point

- Find length of loop
- Find first node of loop → just did it, ie we have to calculate A

Just fix slow point and move fast one step ahead and then increment the count till it reaches the same position.

Delete the node with only pointer given to it:-

I/P - 10 → 20 → 30 → 40 → 50

reference of node 30 is given

O/P → 10 → 20 → 40 → 50

Trick → copy the content of next node to the current node whose pointer is given and then delete the next node

void deleteNode (Node \*ptr) {

Node \*temp = ptr->next

ptr->data = temp->data;

ptr->next = ptr->next->next;

delete (ptr); } 9

\* will not work for last node

## Segregate Even and Odd value in linked list.

I/P  $\rightarrow$  17  $\rightarrow$  15  $\rightarrow$  8  $\rightarrow$  12  $\rightarrow$  10  $\rightarrow$  5  $\rightarrow$  4

O/P  $\rightarrow$  8  $\rightarrow$  12  $\rightarrow$  10  $\rightarrow$  4  $\rightarrow$  17  $\rightarrow$  15  $\rightarrow$  5

I/P  $\rightarrow$  8  $\rightarrow$  12  $\rightarrow$  10

O/P  $\rightarrow$  8  $\rightarrow$  12  $\rightarrow$  10

- we maintains pointers like Evenstart (ES), Eventail (ET), Oddstart (OS), Oddtail (OT)

① whenever we see a even node we append it after eventail, same goes with odd.

② At the end , we just append the odd start after even tail.

Node \* segregate (Node \* head) {

```
Node * es = NULL, * et = NULL, * os = NULL, ot = NULL;
for (Node * curr = Head, curr != NULL; curr =
    curr->next){
```

```
    int x = curr->data;
```

```
    if (x % 2 == 0) {
```

```
        if (es == NULL) {
```

```
            es = curr;
```

```
            et = es;
```

```
        } else {
```

```
            et->next = curr;
```

```
            et = et->next;
```

```
        } else {
```

```
            ot = NULL; curr; oe = ot;
```

```
        } else {
```

```
            ot->next = curr;
```

```
            ot = ot->next;
```

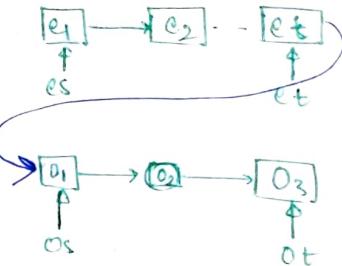
```
        }
```

// After for loop

'if (et == NULL || et == NULL)  
 return head;

else et->next = os;  
 os->next = NULL;  
 return es;

}



## Intersection point of two linked list

I/P  $\rightarrow$  5  $\rightarrow$  10  $\rightarrow$  15  $\rightarrow$  12  $\rightarrow$  15  $\rightarrow$  NULL

O/P  $\rightarrow$  15

### Method-1

- \* Create a hash set storing every node we encounter
- \* As soon as we found a node whose address is already present that is an intersection

$O(n)$  space

$O(n+m)$  time complexity

### Method-2

- ① count the number of nodes in both the list as  $C_1$  and  $C_2$

- ② Now Traverse the bigger list  $\text{abs}(C_1 - C_2)$ -times

- ③ Now both the list at same speed and they will meet at intersection point

Pairwise swap nodes.

I/P  $\rightarrow$  1  $\rightarrow$  2  $\rightarrow$  3  $\rightarrow$  4  $\rightarrow$  5  $\rightarrow$  6

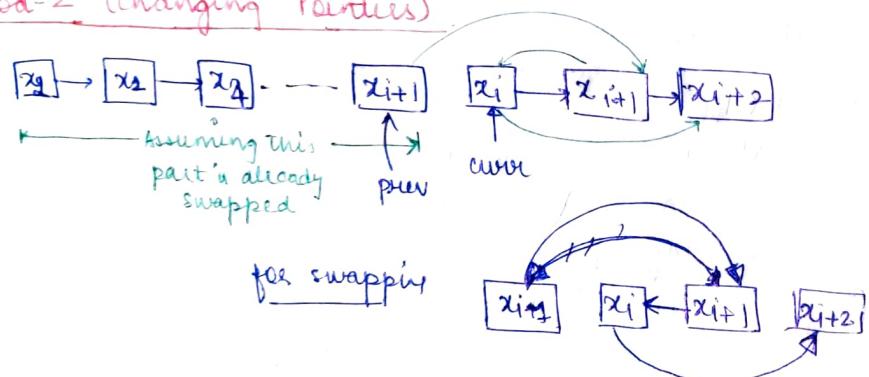
O/P  $\rightarrow$  2  $\rightarrow$  1  $\rightarrow$  4  $\rightarrow$  3  $\rightarrow$  6  $\rightarrow$  5

### Method-1 (swapping data)

Swap the values of curr and curr  $\rightarrow$  next ~~and~~  
+ move curr to curr  $\rightarrow$  next  $\rightarrow$  next.

```
void pairswap(Node *head){  
    Node *curr = head;  
    while (curr != NULL & curr  $\rightarrow$  next != NULL){  
        swap(curr  $\rightarrow$  data, curr  $\rightarrow$  next  $\rightarrow$  data)  
        curr = curr  $\rightarrow$  next  $\rightarrow$  next;  
    }  
}
```

### Method-2 (changing Pointers)



```
Node *pairswap_better(Node *head){
```

```
    Node *curr = head, *next, *prev = NULL;  
    *temp = NULL;
```

```
    while (curr != NULL & curr  $\rightarrow$  next != NULL){  
        next = curr  $\rightarrow$  next  $\rightarrow$  next;  
        temp = curr  $\rightarrow$  next;  
        temp  $\rightarrow$  next = curr;
```

curr  $\rightarrow$  next = next;

if (prev != NULL)

    prev  $\rightarrow$  next = temp;

else

    head = temp;

    prev = curr;

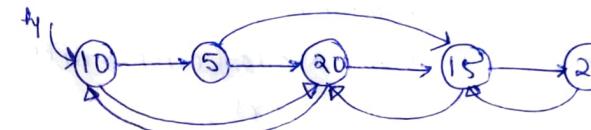
    curr = next;

}

return head;

y.

Clone the linked list with Random pointers



### Method-1

Using hash maps.

① Create a hashmap, m.

② for (curr = h1 ; curr != NULL ; curr = curr  $\rightarrow$  next)  
    m[curr] = new Node (curr  $\rightarrow$  data);

③ for (curr = h1 ; curr != NULL ; curr = curr  $\rightarrow$  next)  
    {  
        clone curr = m[hash[curr]]  
        clone curr  $\rightarrow$  next = m[hash[curr  $\rightarrow$  next]]  
        clone curr  $\rightarrow$  random = m[curr  $\rightarrow$  random]  
    }  
y.

Node \*head2 = m[head];

return head2;

y.



## Simple Implementation - Array

Time complexity -  $O(n)$  of both hit and miss  
 $n \rightarrow$  capacity of cache.

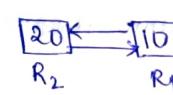
## Effective approach

- use of hashing for quick access and insert
- use of doubly linked list to maintain order

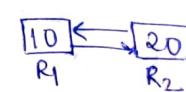
10; Miss (10, R<sub>1</sub>)



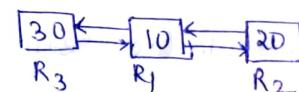
20; Miss (10, R<sub>1</sub>) (20, R<sub>2</sub>)



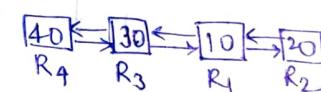
10; Hit No change



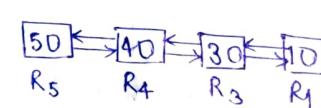
30; Miss (10, R<sub>1</sub>) (20, R<sub>2</sub>)  
(30, R<sub>3</sub>)



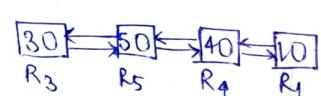
40; Miss (40, R<sub>4</sub>) (10, R<sub>1</sub>)  
(20, R<sub>2</sub>) (30, R<sub>3</sub>)



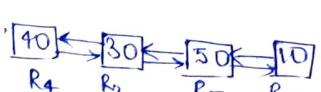
50; Miss (10, R<sub>1</sub>) (30, R<sub>3</sub>)  
(40, R<sub>4</sub>) (50, R<sub>5</sub>)



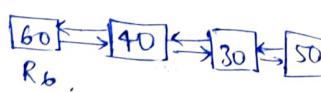
30; Hit No change



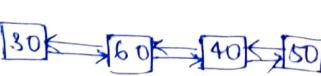
40; Hit No change



60; Miss (40, R<sub>4</sub>), (30, R<sub>3</sub>)  
(50, R<sub>5</sub>), (60, R<sub>6</sub>)



30; Hit No change



- using the tail pointer we can remove the last node, when cache the full.
- Removal of any middle node is possible in  $O(1)$  time in doubly linked list -
- doubly linked list works as queue, but supports additional operation of moving the middle item (hit) in the front.

Refer(x) {

Look for x in the Hash table.

- If found (hit), find the reference of the node. ~~Move~~ Move it to front.
- If Not found (miss).
  - Insert a new node at front of DLL
  - Insert an entry into the H.T

## Merge Sorted linked list

I/P : a: [10] → [20] → [30]      b: [5] → [25]

O/P : [5] → [10] → [20] → [25] → [30]

We maintain four pointers

- a → curr element in A
- b → curr element in B
- head → head of resultant
- tail → tail of res.

Node \*sortedMerge (Node \*a1, Node \*a2) {

if (a1 == NULL) return a2;

if (a2 == NULL) return a1;

Node \*head = NULL, \*tail = NULL;

Node \*a = a1, \*b = a2;

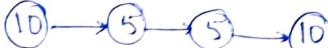
```

if(a->next)
    if(a->data <= b->data) {
        head = a;
        a = a->next;
    } else {
        head = b;
        b = b->next;
    }
    tail = head;
    while(a != NULL || b != NULL) {
        if(a->data <= b->data) {
            tail->next = a;
            a = a->next;
        } else {
            tail->next = b;
            b = b->next;
        }
        if(a == NULL) tail->next = b;
        else tail->next = a;
    }
    return head;
}

```

Auxiliary space - O(1)  
Time complexity - O(m+n)

### Palindrome linked list

I/P - 

O/P - Yes

I/P - 

O/P - Yes

I/P - 

O/P - No.

### Naive solution

- ① use a stack and push all the elements into it
- ② run second loop and check if it is equal to curr->data.

```

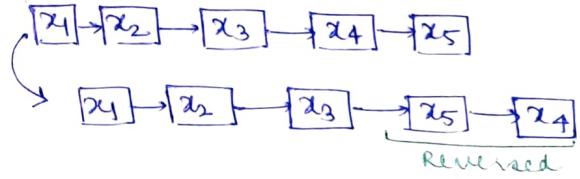
bool isPalindrome (Node * head) {
    stack<int> st;
    for (Node * curr = head; curr != NULL; curr = curr->next) {
        st.push(curr->data);
    }
    for (Node * curr = head; curr != NULL; curr = curr->next) {
        if (st.top() != curr->data)
            return false;
    }
    return true;
}

```

$O(n)$  with two traversal  
 $O(n)$  space

### Efficient Approach

- Find the middle point and reverse the second part
- Now one by one compare first half and reversed second half.



compare one by one.

$x_1$  with  $x_5$

$x_2$  with  $x_4$

;

;

```
bool isPalindrome (Node *root) {
    if (head == NULL) return true;
    Node *slow = head, *fast = head;
    while (fast->next != NULL &&
           fast->next->next != NULL) {
        slow = slow->next;
        fast = fast->next->next;
    }
    Node *rev = reverseList (slow->next);
    Node *curr = head;
    while (rev != NULL) {
        if (rev->data != curr->data)
            return false;
        rev = rev->next;
        curr = curr->next;
    }
    return true;
}
```