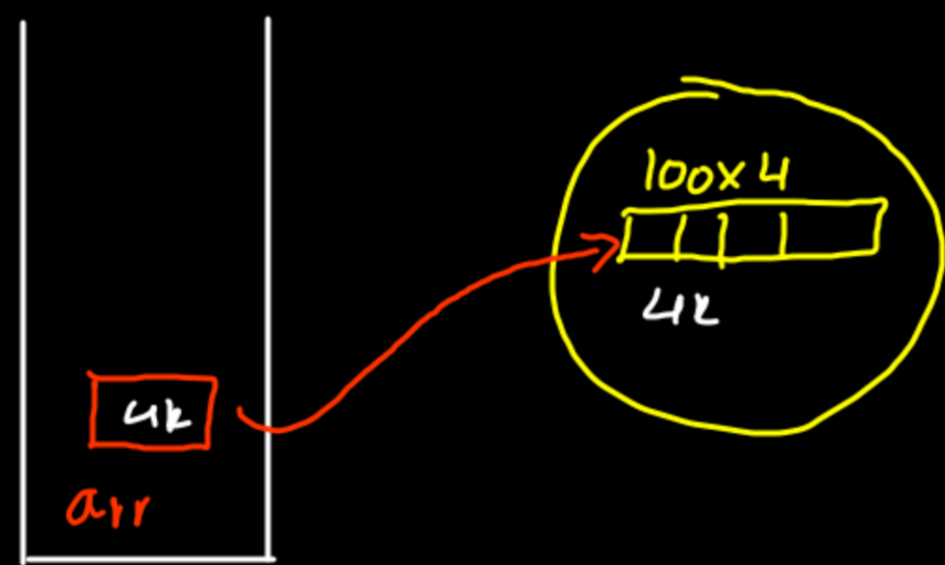
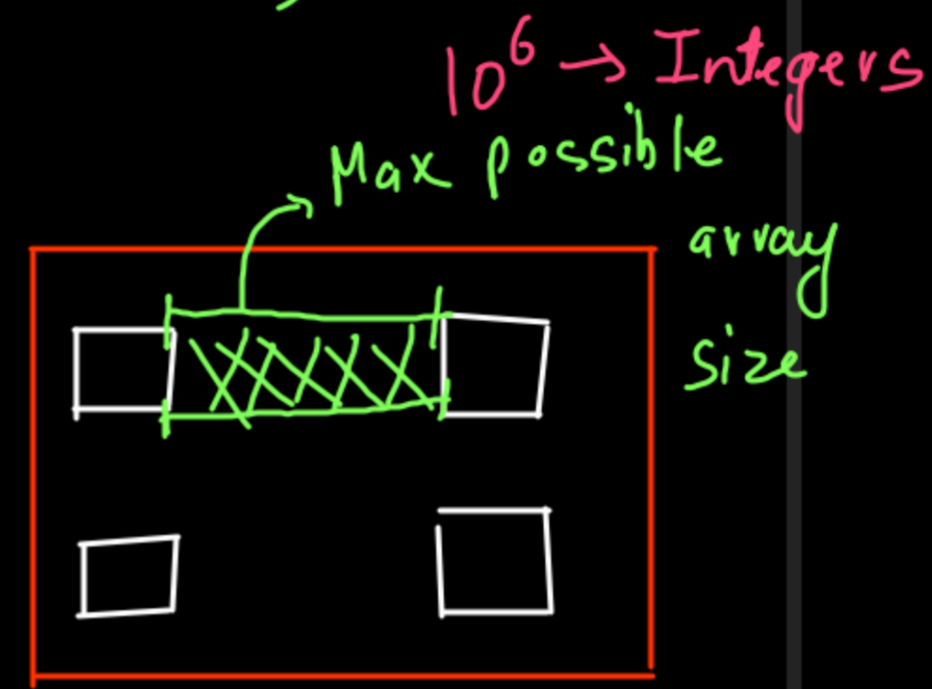
Linked List (Level 1+2)

Arrays

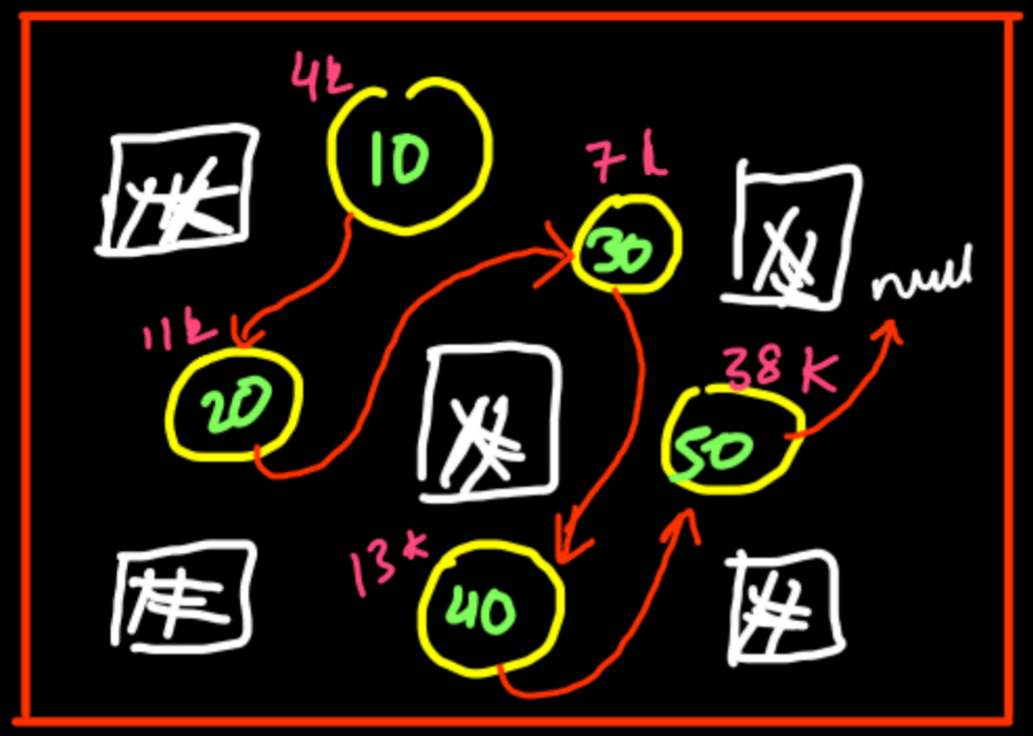
```
int [] arr = new int [100];
```





fragmentation issue (Memory got divided into fragments & enough Mem not avail)

Linked List: Non contiguous memory allocation.



We need links to connect data.

10, 20, 30, 40, 50

4k 11k 7k 13K 38k

```
Node {object} {
    int data;
    Node next;
}
```

Address of Next Node

```
public static Node {
    int data;
    Node next;
}
```

Inner class ko static banana hai.

```java
public static class Node {
    int data;
    Node next; //self referential data member
}
```

class → data members, functions

We only need one node (first Node) to get all the elements of the linked list because second ele will get from first's next & so on.

```java
public static class LinkedList {

    Node head;

    public void display() {

    }

    public void addFirst(int data) {

    }

    public void addLast(int data) {

    }

    public int get(int index) {

    }

}
```

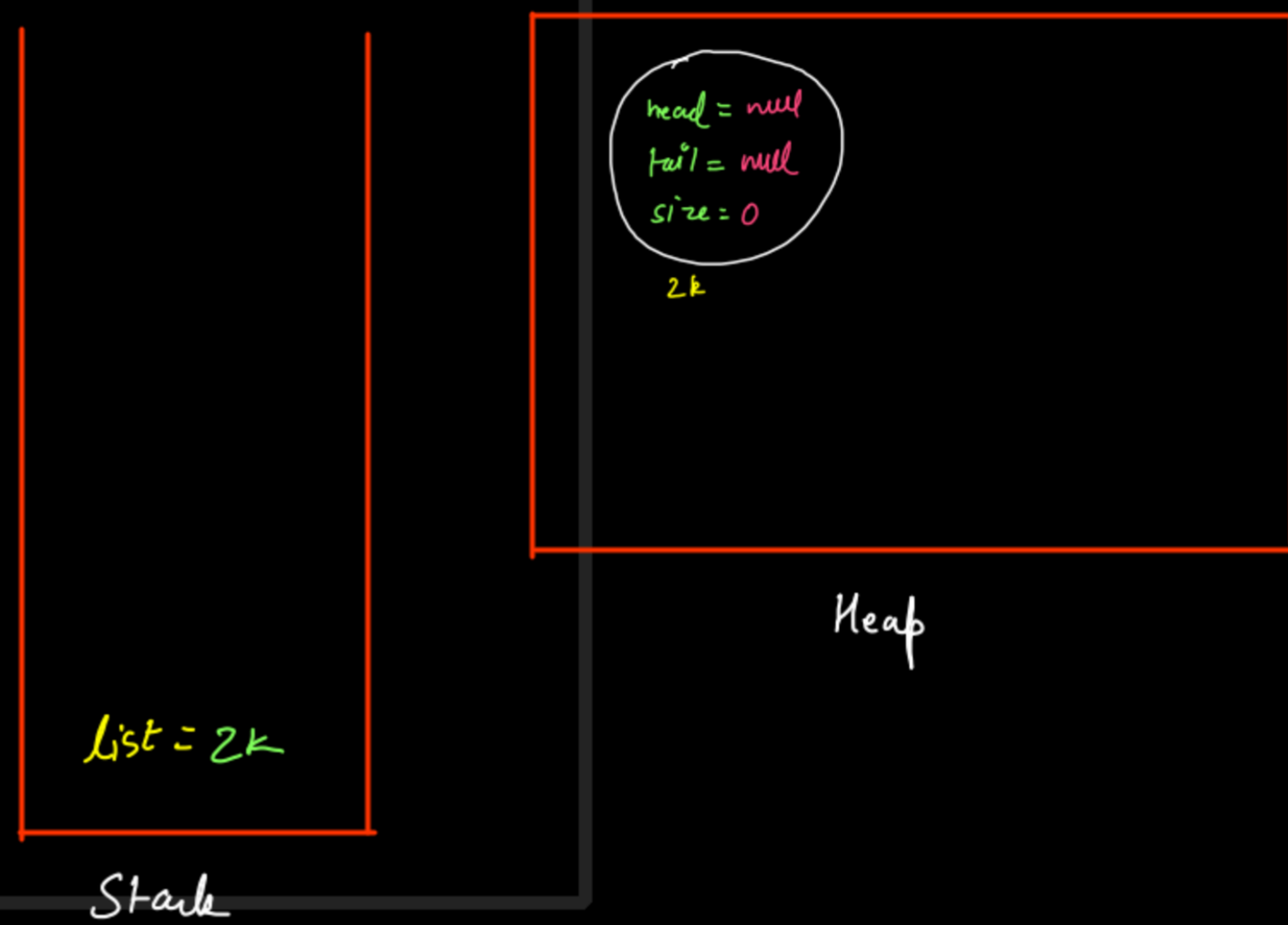
```java
public static class Node {
    int data;
    Node next; //self referential data member
}
```

```java
public static class LinkedList {

    Node head;
    Node tail;
    int size;

    public void display() {

    }

    public void addFirst(int data) {

    }

    public void addLast(int data) {

    }

    public int get(int index) {

    }

}
```

psv main() {

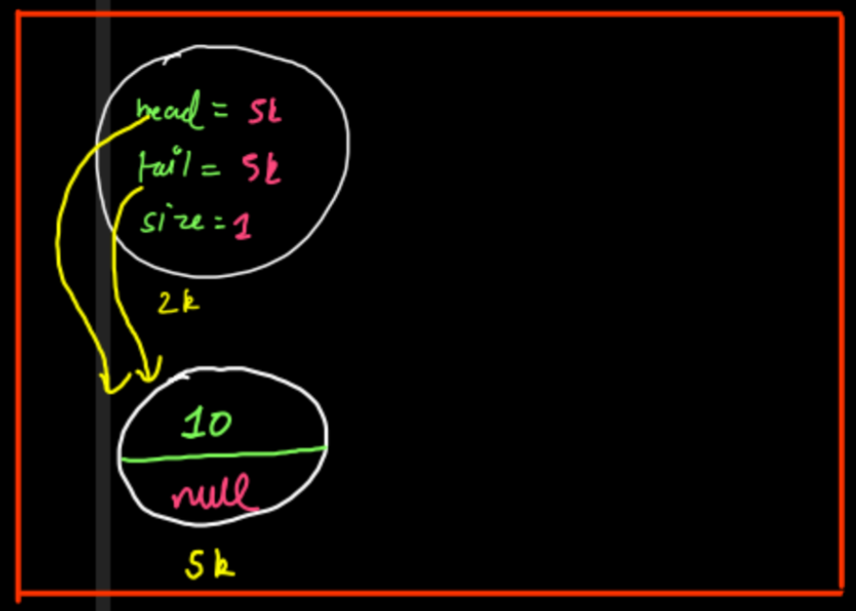
LinkedList list = new LinkedList();

}

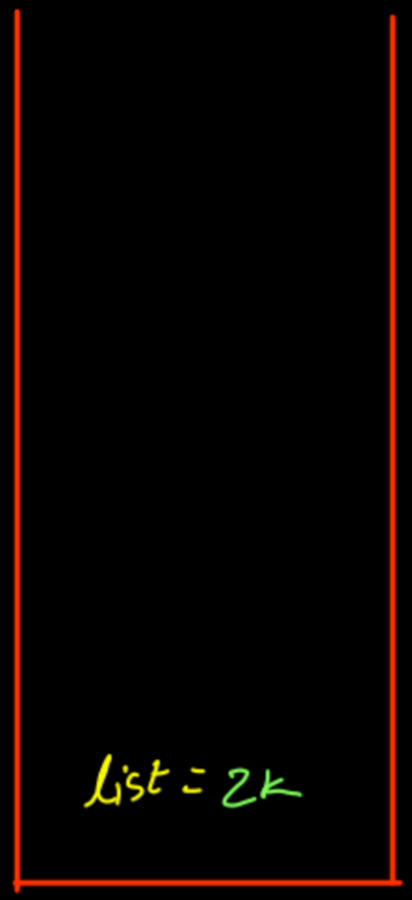


```java
public static class Node {
    int data;
    Node next; //self referential data member
}
```

```java
public static class LinkedList {

    Node head;
    Node tail;
    int size;

    public void display() {

    }

    public void addFirst(int data) {

    }

    public void addLast(int data) {

    }

    public int get(int index) {

    }

}
```



Heap



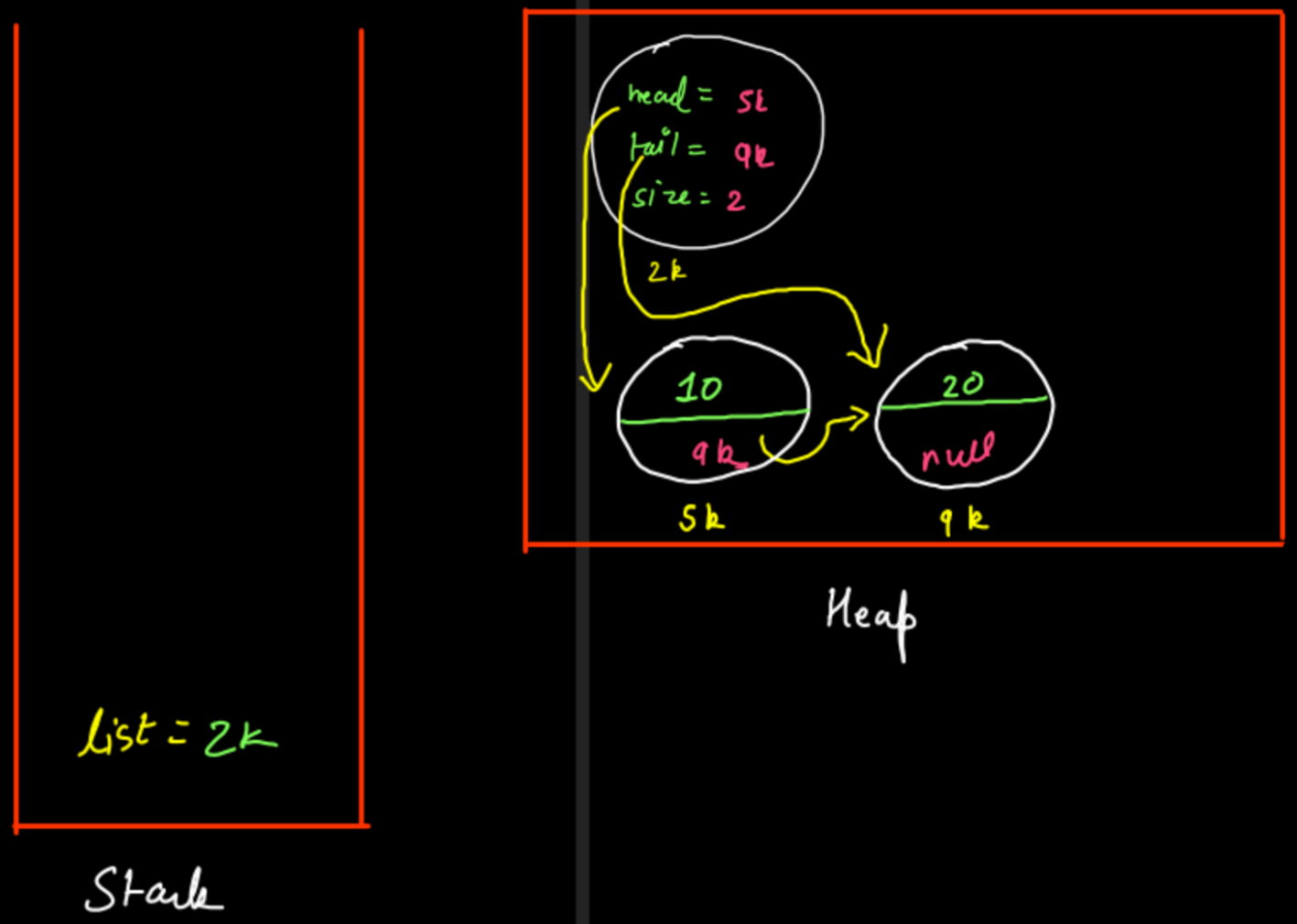
Stack

```java
psv main() {
LinkedList list = new LinkedList();
list.addLast(10);
}
```

```java
public static class Node {
    int data;
    Node next; //self referential data member
}
```

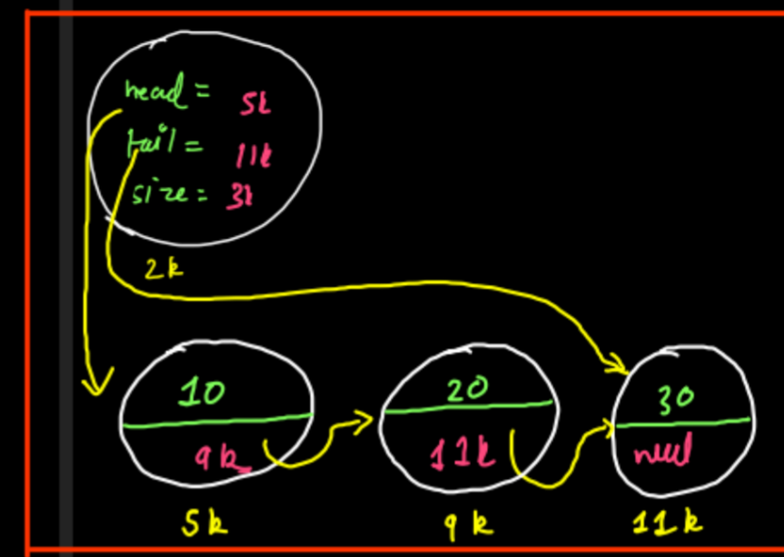
```java
public static class LinkedList {

    Node head;
    Node tail;
    int size;

    public void display() {

    }

    public void addFirst(int data) {

    }

    public void addLast(int data) {

    }

    public int get(int index) {

    }

}
```

```java
psv main() {
LinkedList list = new LinkedList();
list.addLast(10);
list.addLast(20);
}
```

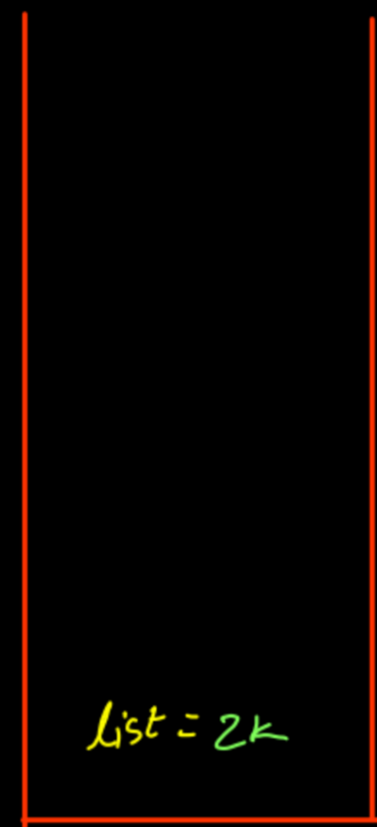


```java
public static class Node {
    int data;
    Node next; //self referential data member
}
```

```java
public static class LinkedList {

    Node head;
    Node tail;
    int size;

    public void display() {

    }

    public void addFirst(int data) {

    }

    public void addLast(int data) {

    }

    public int get(int index) {

    }

}
```



Heap



Stack

LL is taking lot of extra space
Random Access is not allowed in LL

psv main() {

LinkedList list = new LinkedList();

list.addLast(10);

list.addLast(20);

list.addLast(30);

}

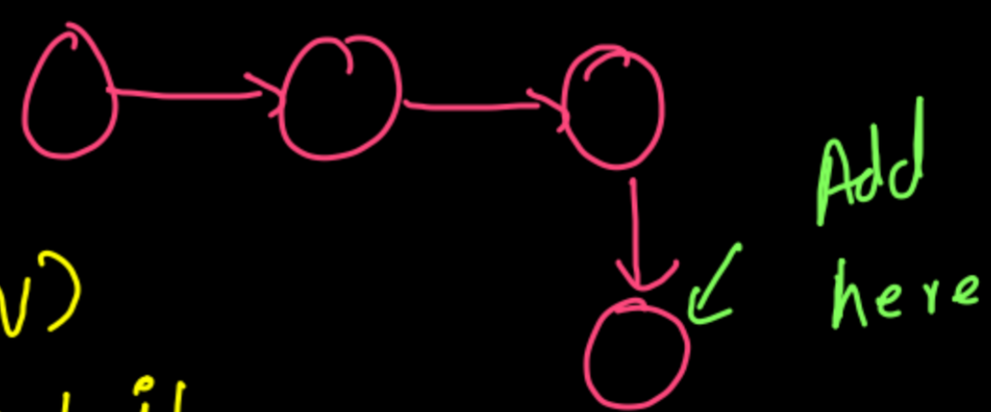
** Size of reference is unknown in LL.

Add Last Code

```
void addLast(int val) {
    // Write your code here
    Node temp = new Node();
    temp.data = val;

    if(size == 0) {
        head = temp;
        tail = temp;
    } else {
        tail.next = temp;
        tail = temp;
    }

    size++;
}
```

TC = O(1) → using tail
addLast is a
constant operation

#If tail is not given



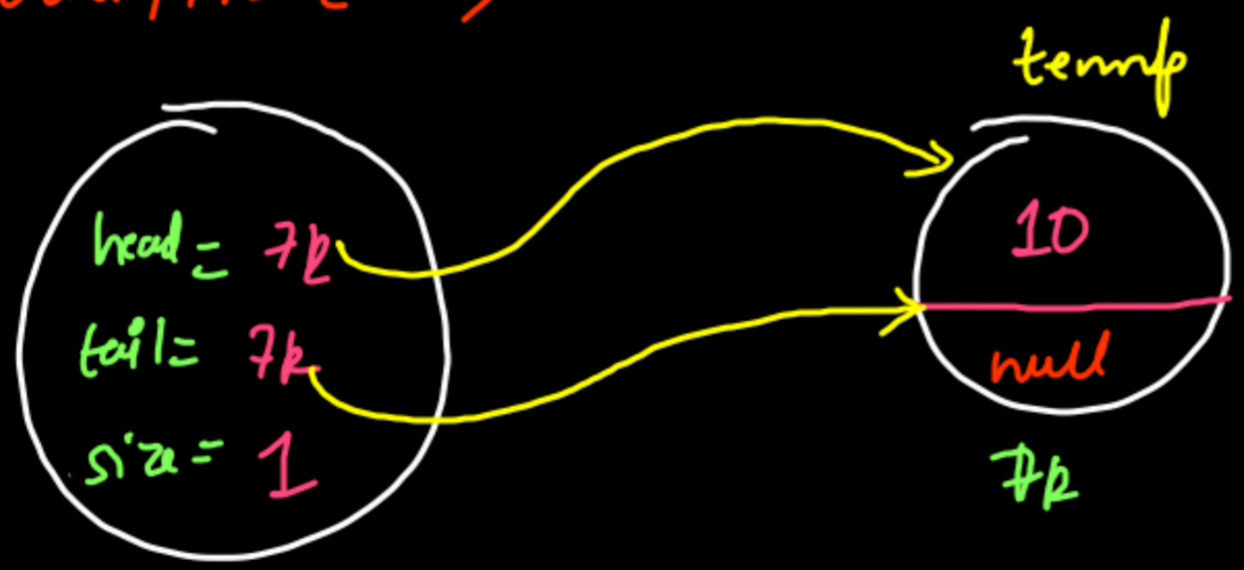
TC = O(N)
without tail

Add first

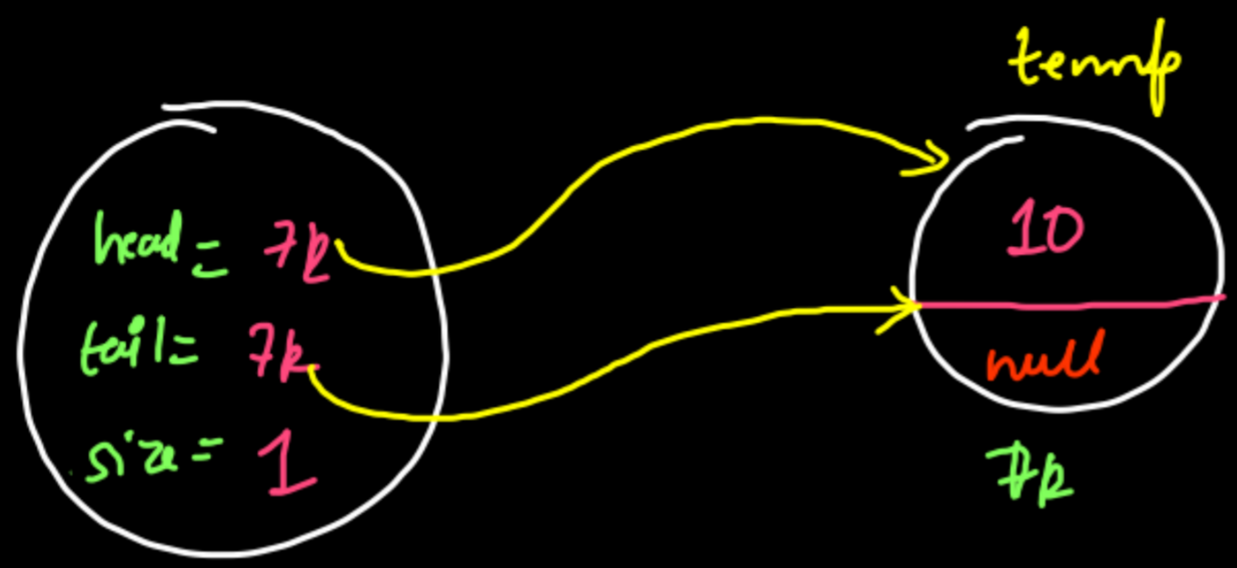
```
LinkedList list = new LinkedList();
```

head = null
tail = null
size = 0

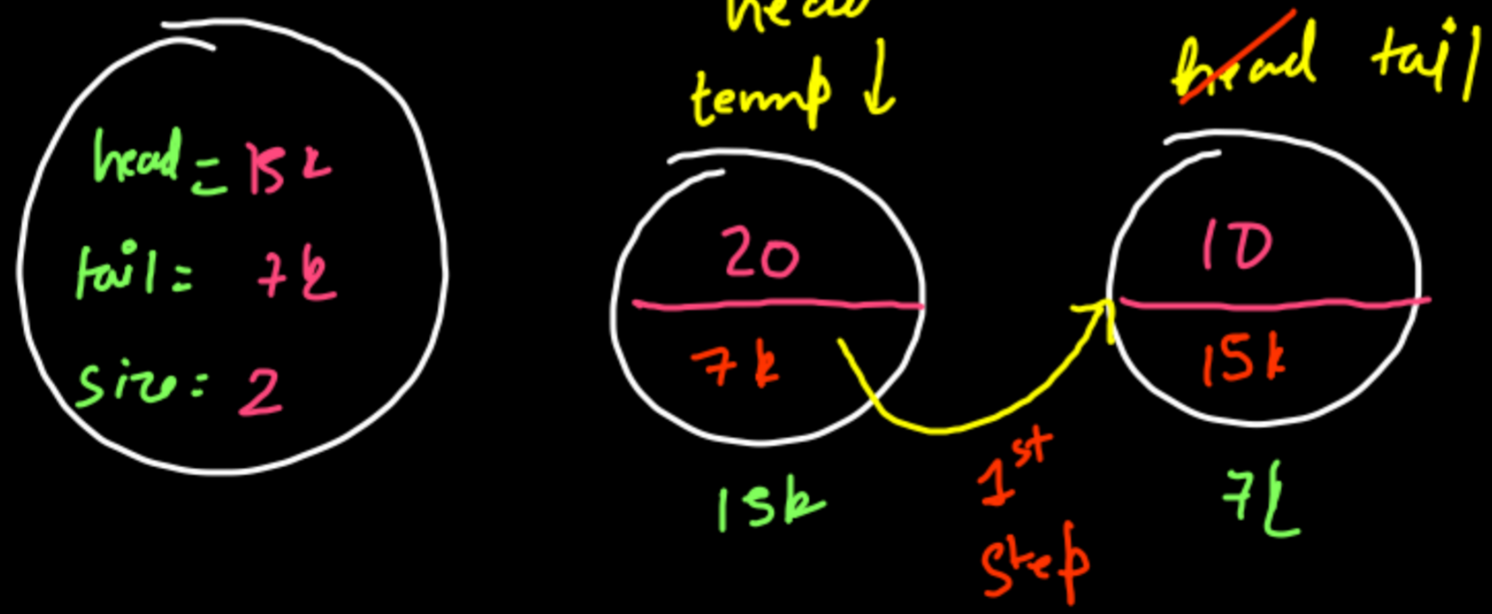
add first(10);




```
if (size == 0)
{ head = temp;
  tail = temp;
}
```



addfirst (20);



if size != 0

1 temp.next = head;

2 head = temp;

Add first Code

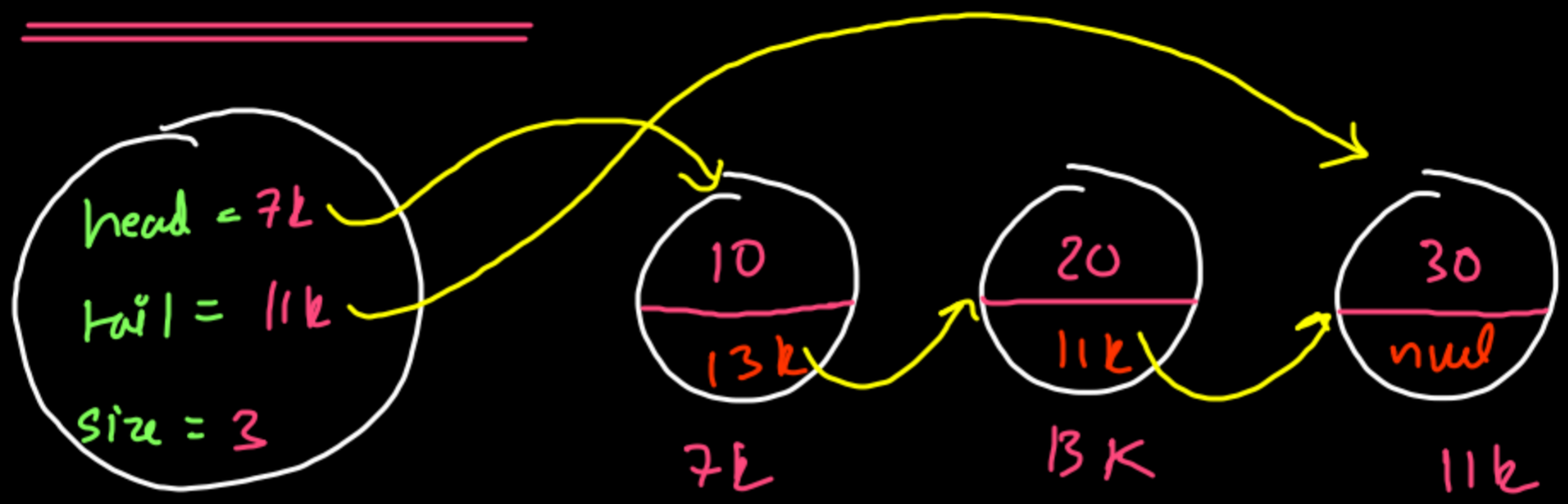
```java
public void addFirst(int val) {
    // write your code here

    Node temp = new Node();
    temp.data = val;

    if(size == 0) {
        head = temp;
        tail = temp;
    } else {
        temp.next = head;
        head = temp;
    }

    size++;
  }
}
```

TC = O(1)

⇓

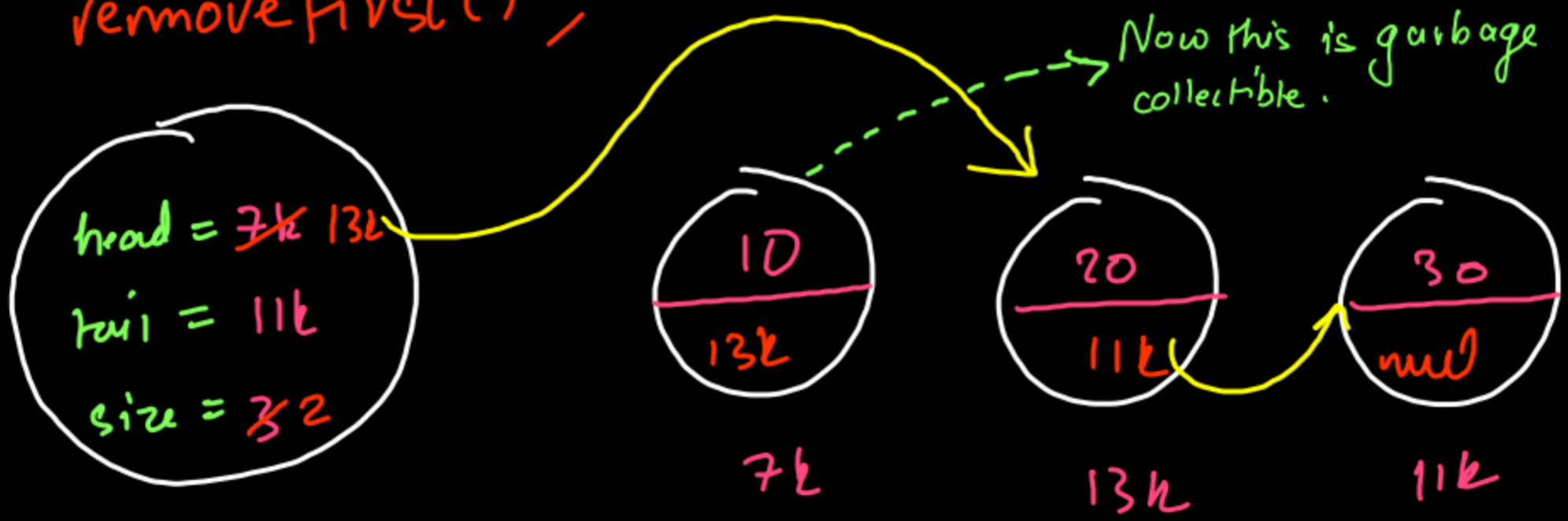
always constant because head will always be there.

Remove first



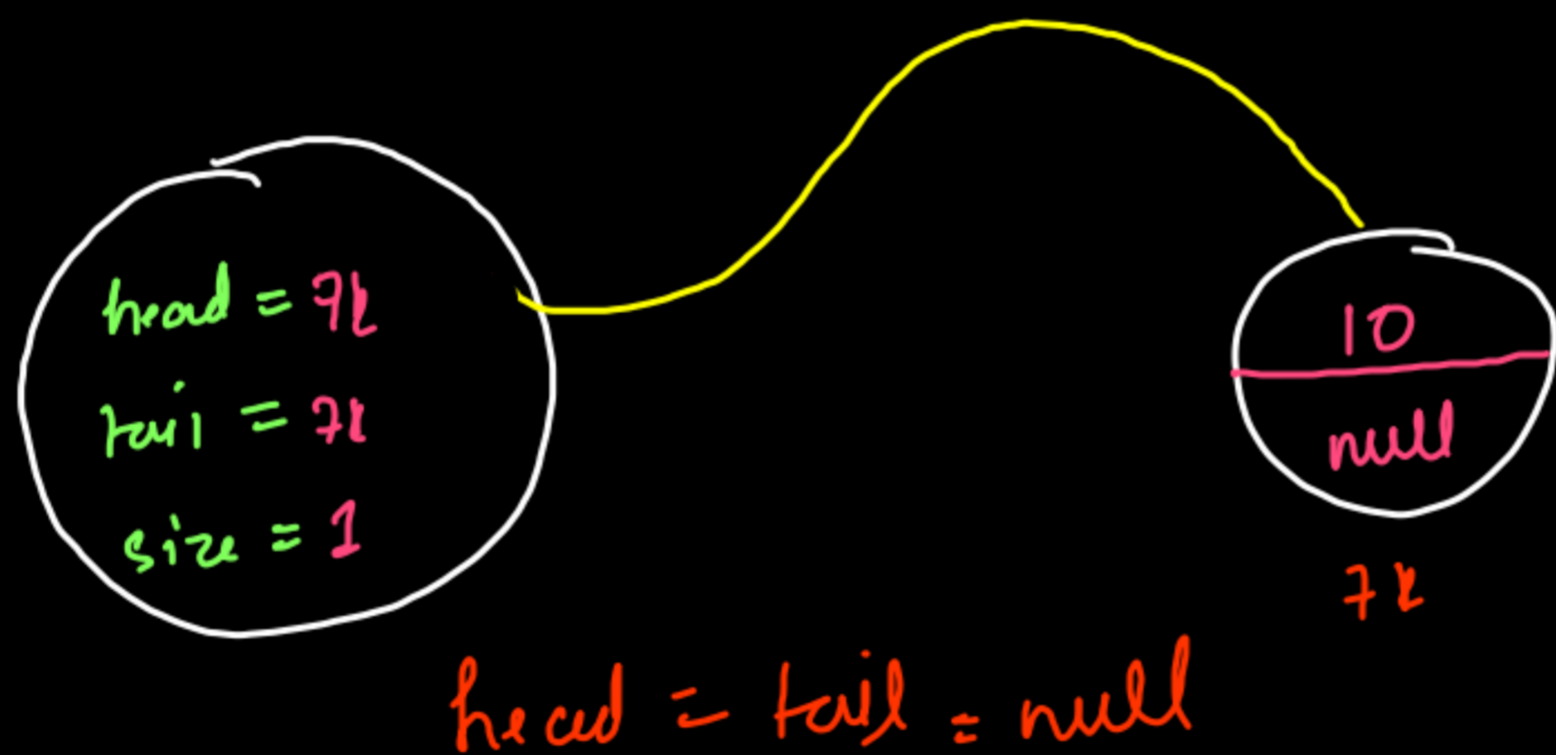

```
removeFirst();
```

```
if (size>1) head = head.next;
```



if size is 1 then deleting node will empty the LL.

when LL is empty, $\boxed{\text{head} = \text{tail} = \text{null}}$



Removefirst Code

```java
public void removeFirst(){
    // write your code here
    if(size == 0) {
        System.out.println("List is empty");
        return;
    }

    if(size == 1) {
        head = tail = null;
    } else {
        head = head.next;
    }

    size--;
}
```

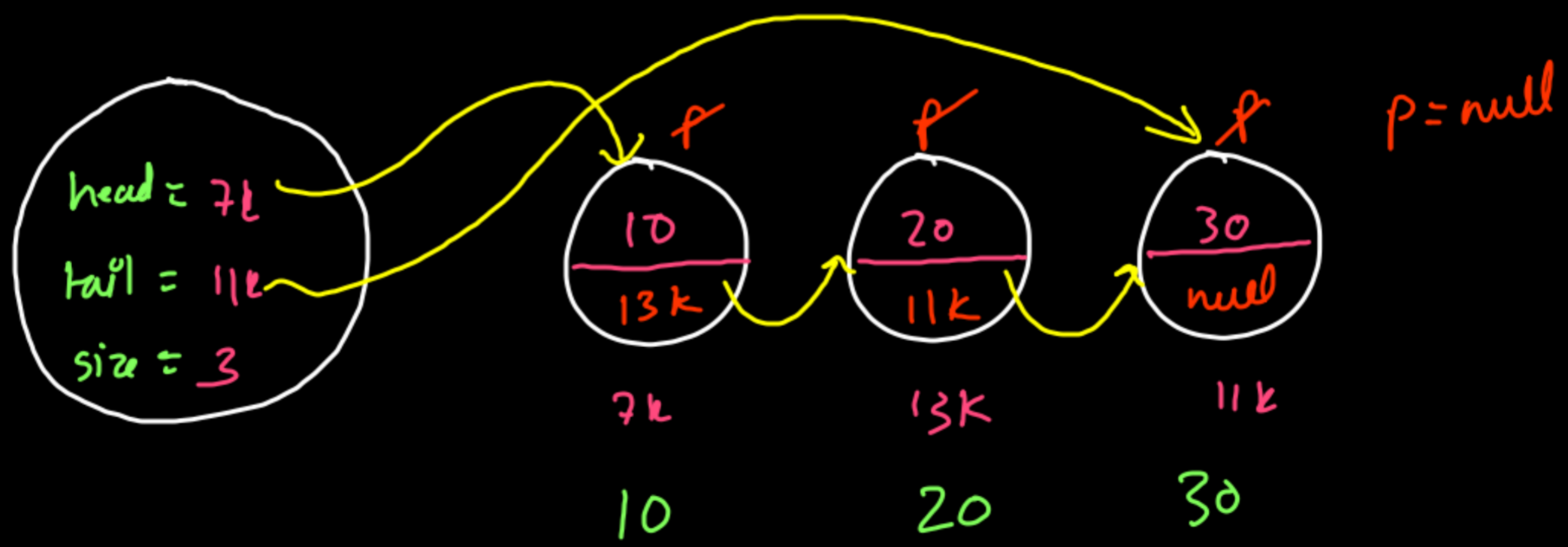
Display List

Using size

```java
public void display(){
    // write code here

    if(size == 0) return;

    Node p = head;

    for(int i=1;i<=size;i++) {
        System.out.print(p.data + " ");
        p = p.next;
    }
    System.out.println();
}
```

Without using size.

```java
public void display(){
    // write code here

    if(size == 0) return;

    Node curr = head;

    while(curr != null) {
        System.out.print(curr.data + " ");
        curr = curr.next;
    }
    System.out.println();
}
}
```



Get Value in LL

Get first ()

return head.data;
else return -1;

In case of invalid index
print "Invalid arguments"

If list is empty print "List is empty"

Get Last ()

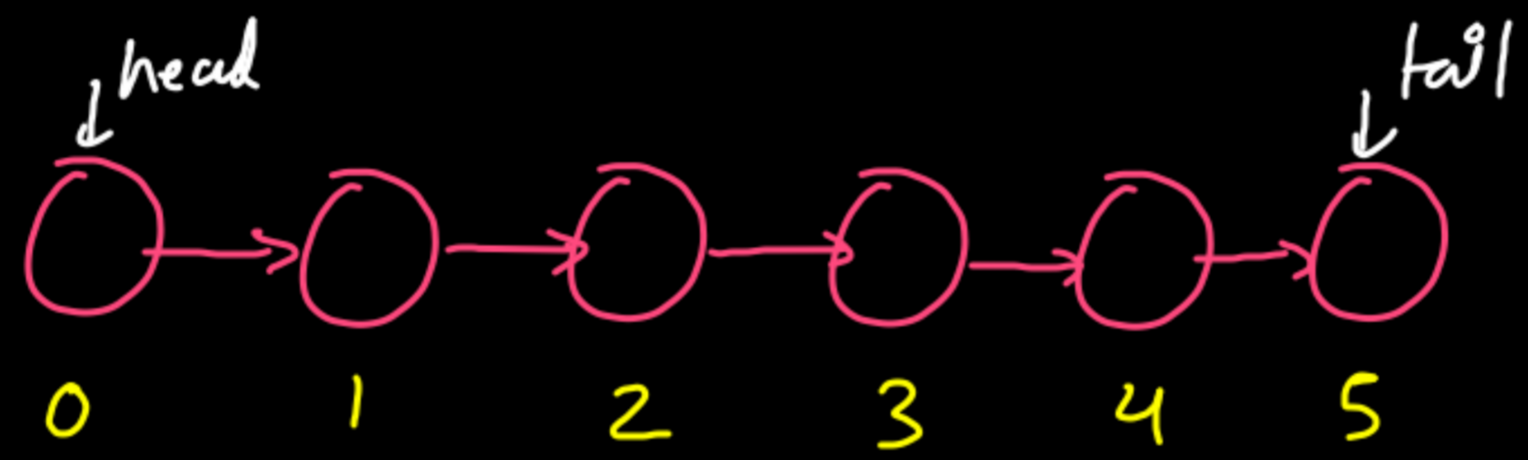
return tail.data;
else return -1;

In case of invalid index
print "Invalid arguments"

If list is empty print "List is empty"

GetAt(Index)

Indexing is 0 based



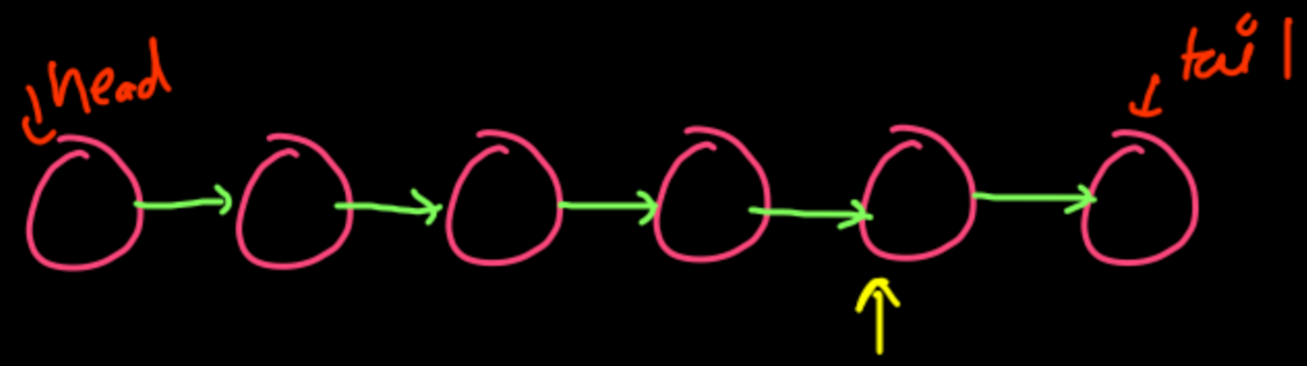
Apply a Loop now starting from 0 to idx -1
& return curr. data.

All Get Codes

```java
public int getFirst(){
  // write your code here
  if(size == 0) {
      System.out.println("List is empty");
      return -1;
  } else {
      return head.data;
  }
}

public int getLast(){
  // write your code here
  if(size == 0) {
      System.out.println("List is empty");
      return -1;
  } else {
      return tail.data;
  }
}
```

```java
public int getAt(int idx){
  // write your code here
  if(size == 0) {
      System.out.println("List is empty");
      return -1;
  }

  if(idx < 0 || idx >= size) {
      System.out.println("Invalid arguments");
      return -1;
  }

  if(idx == 0) return getFirst();

  if(idx == size - 1) return getLast();

  Node curr = head;

  for(int i=0;i<idx;i++) {
    curr = curr.next;
  }

  return curr.data;
}
}
```

Removelast



we need previous of tail to delete tail.

Hence, even if we have tail, we have to traverse the LL to delete the lastNode.

Hence, the Time Complexity will always be O(N).

① Go till prev of tail.

```
Node prevTail = get(size-2);
prevTail.next = null;
tail = prevTail;
```

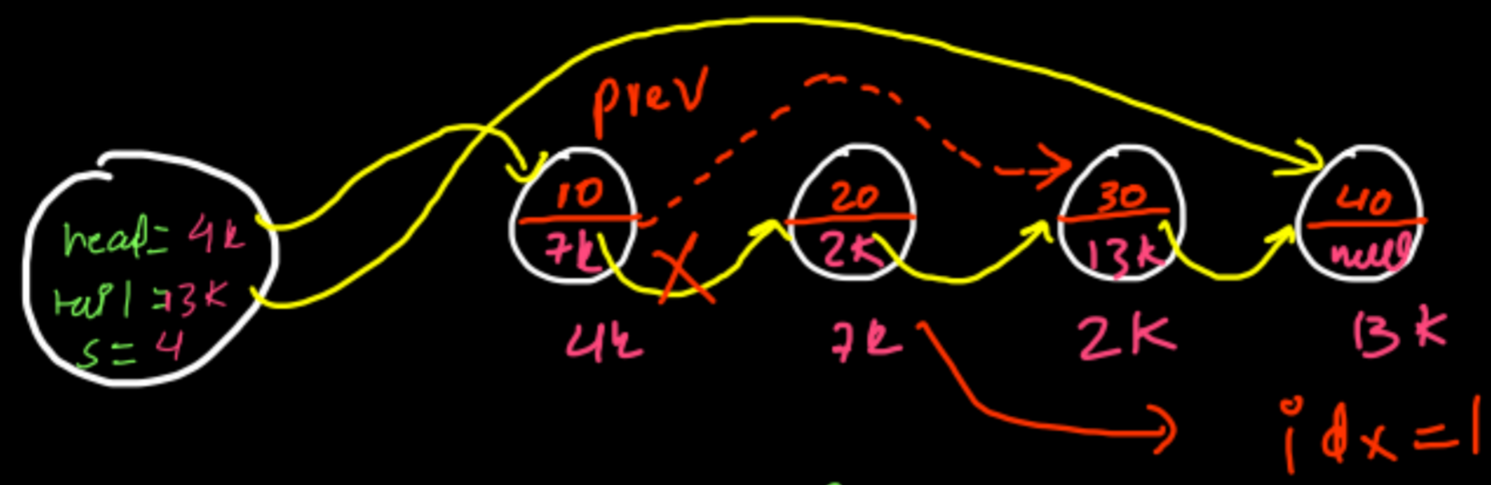
size > 0

```
if (size == 1)
    head = tail = null;
```

Remove Last Code

```java
public void removeLast(){
  // write your code here
  if(size == 0) {
      System.out.println("List is empty");
      size--;
      return;
  }

  if(size == 1) {
      head = tail = null;
      size--;
      return;
  }

  Node curr = head;
  for(int i=0;i<size-2;i++) {
      curr = curr.next;
  }

  curr.next = null;
  tail = curr;

  size--;
 }
}
```

Remove At



1) idx == 0 → removefirst();

2) idx == size - 1 → removelast();

3) remove At idx → ① Get (idx - 1)th node

0 < idx < size - 1 ② prev.next = prev.next.next

③ size--;

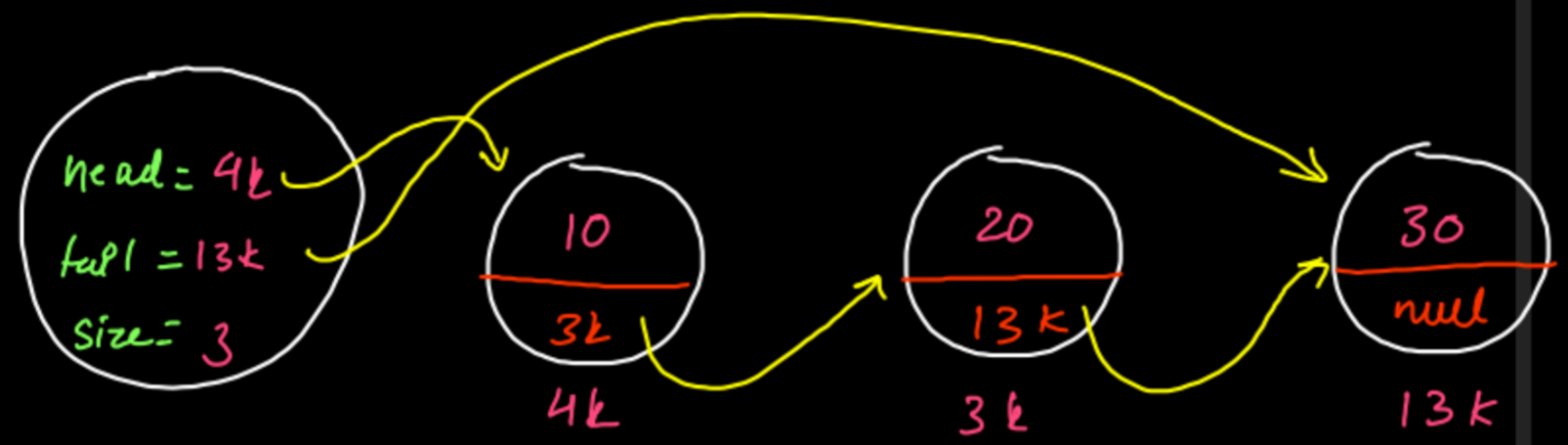
idx < 0 || idx >= size } invalid args

size == 0 } LL is empty

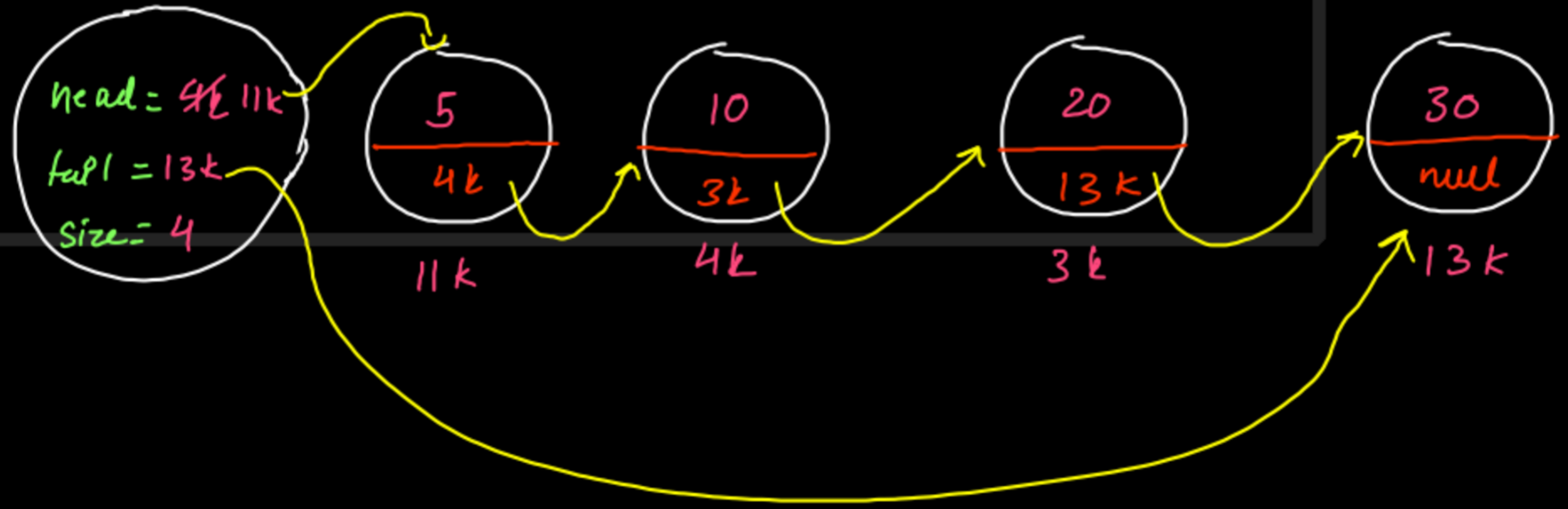
Remove At Code

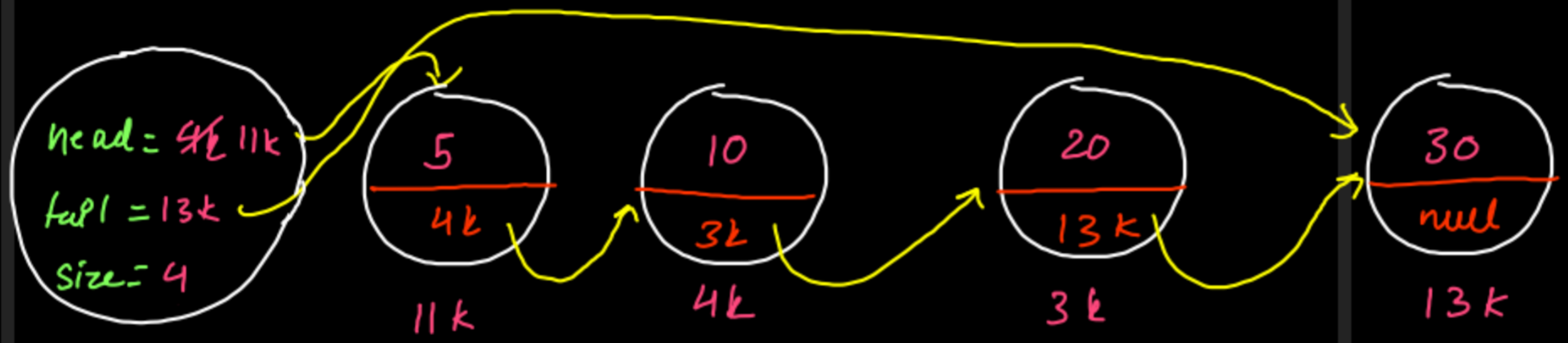
```java
public void removeAt(int index) {
  // write your code here
   if(index < 0 || index >= size) {
        System.out.println("Invalid arguments");
        return;
    }

    if(size == 0) {
        System.out.println("List is empty");
        return;
    }

    if(index == 0) {
        removeFirst();
        return;
    }

    if(index == size - 1) {
        removeLast();
        return;
    }

    Node curr = head;
    for(int i=1;i<index;i++) {
        curr = curr.next;
    }

    curr.next = curr.next.next;
    size--;
}
```

Add At

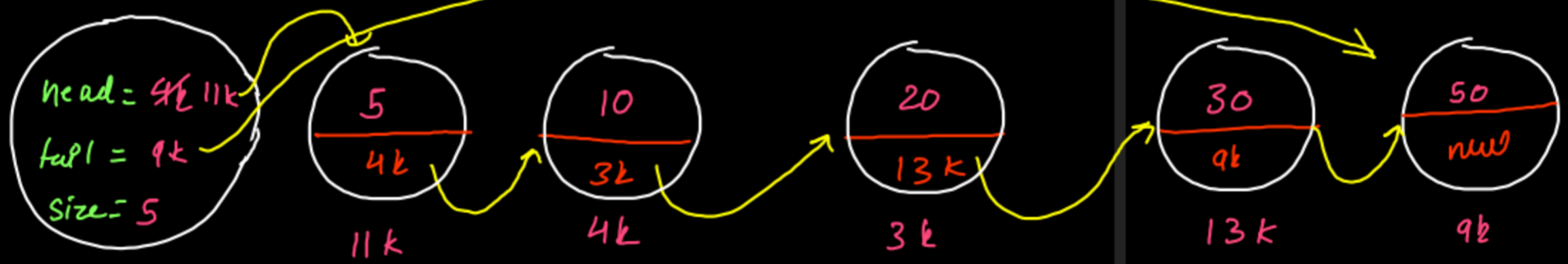


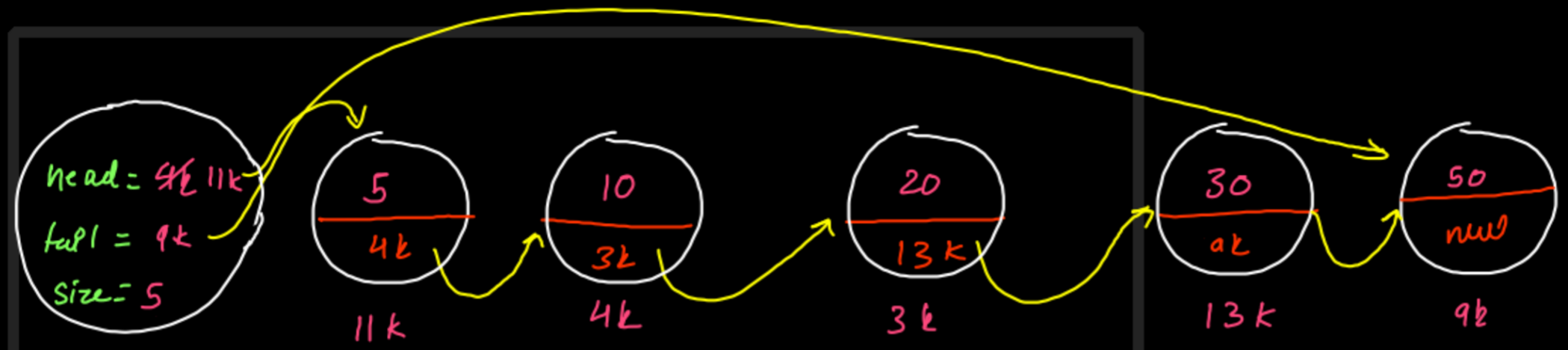
addAt(0,5) -> addFirst();



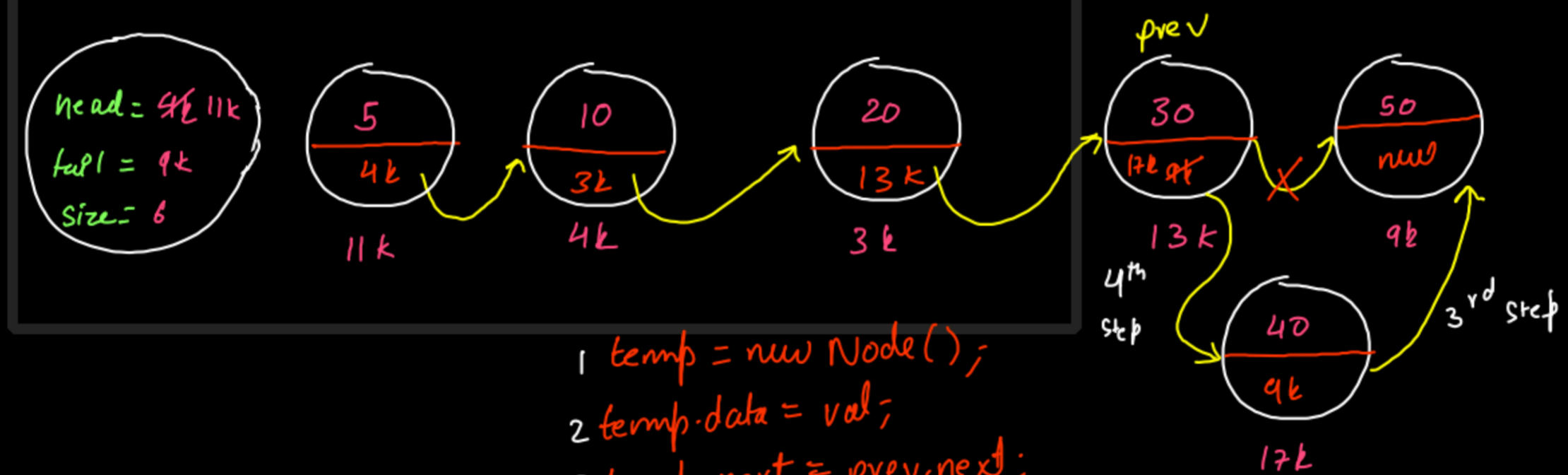


addAt(4, 50) ⇒ addLast()





addAt(4, 40); ⇒ addAt(size-1) is not addAtTail




```
1 temp = new Node();
2 temp.data = val;
3 temp.next = prev.next;
4 prev.next = temp;
```

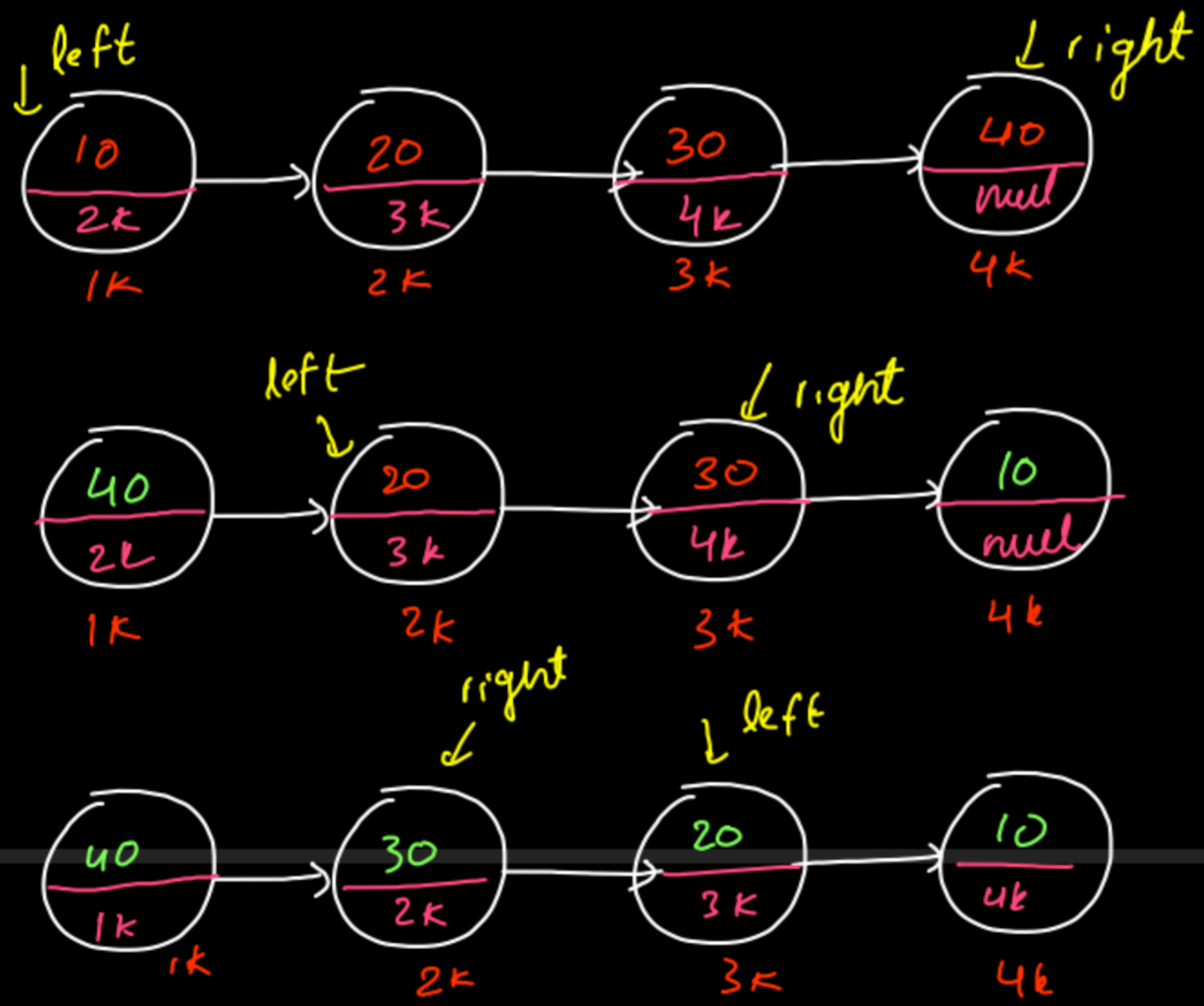
Add At Code

```java
public void addAt(int idx, int val){
  // write your code here

  if(idx < 0 || idx > size) {
      System.out.println("Invalid arguments");
      return;
  }

  if(idx == 0) {
      addFirst(val);
      return;
  }

  if(idx == size) {
      addLast(val);
      return;
  }

  Node prev = head;

  for(int i=1;i<idx;i++) {
      prev = prev.next;
  }

  Node temp = new Node();
  temp.data = val;
  temp.next = prev.next;
  prev.next = temp;
  size++;
 }
}
```

Reverse a Linked List

1. Data Iterative
2. Pointer Iterative
3. Data Recursive
4. Pointer Recursive

Reverse a Linked List Data Iterative



getAt(left)
getAt(right) } O(N)

do this for $\frac{N}{2}$ times

$\frac{N}{2} * O(N)$

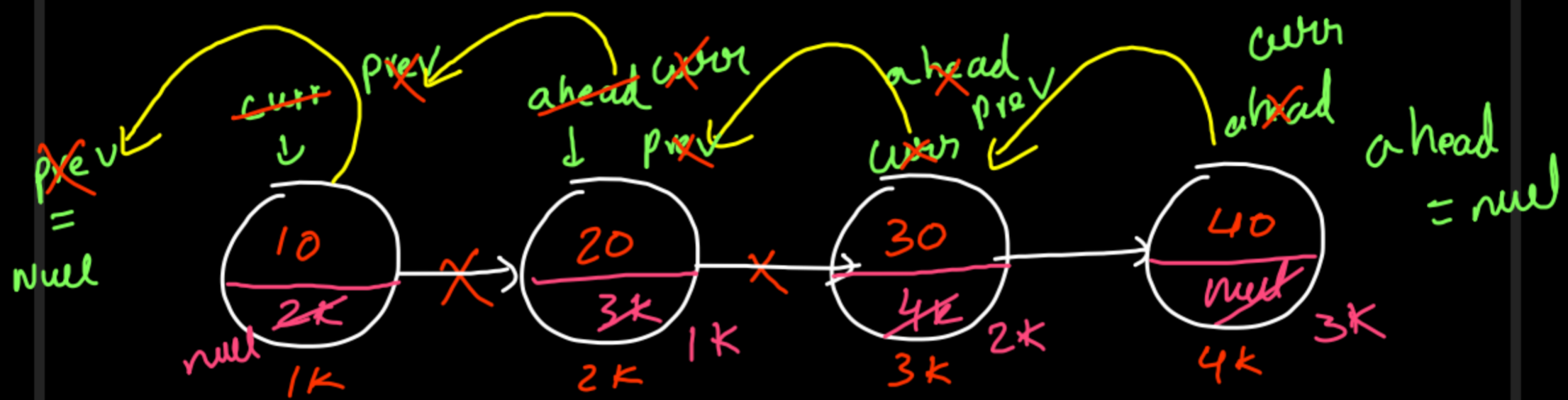
$\Rightarrow TC = O(N^2)$

Reverse DI Code

```
public void reverseDI() {
  // write your code here
  int left = 0;
  int right = size - 1;

  while(left <= right) {
      Node leftNode = getNodeAt(left);
      Node rightNode = getNodeAt(right);
      int temp = leftNode.data;
      leftNode.data = rightNode.data;
      rightNode.data = temp;
      left++;
      right--;
  }
}
```

However it is an $O(n^2)$ approach, it is still the only & best possible approach for reversing LL DI way.

Reverse a Linked List Pointer Iterative



We will need 3 pointers

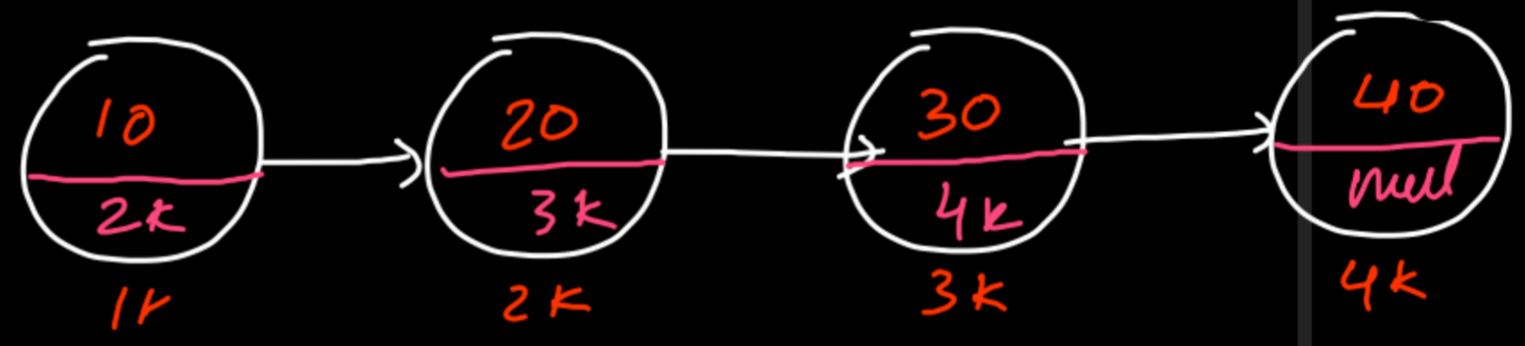
```
curr.next = prev;
prev = curr;
curr = ahead;
```

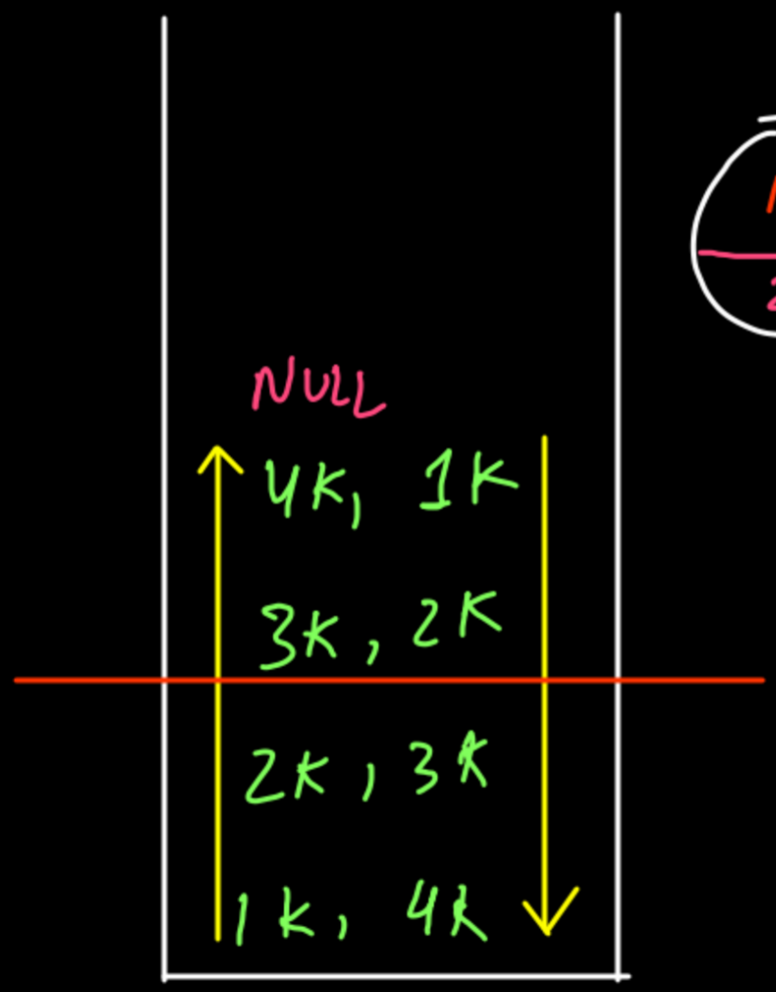
} while (curr != null)

Reverse a LL Pointer Iterative Code

```
public void reversePI(){
    // write your code here
    if(size == 0 || size == 1) {
        return;
    }
    Node prev = null;
    Node curr = head;

    while(curr != null) {
        Node ahead = curr.next;
        curr.next = prev;
        prev = curr;
        curr = ahead;
    }

//   swap head and tail
    Node temp = head;
    head = tail;
    tail = temp;
}
```

Reverse a LL Data Recursive





Do only 1/2 times because else the LL will remain as it is.

30 10 20

~~10~~ → ~~20~~ → ~~30~~ → 40 → 50 → 60 → null

1k 2k 3k 4k 5k 6k

~~l = null~~	
~~l = 6k r = 1k~~ (2)	c = 5
~~l = 5k r = 1k~~ (2)	c = 4
~~l = 4k r = 1k~~ (2)	c = 3
~~l = 3k r = 1k~~ (2)	c = 2
~~l = 2k r = 1k~~ (2)	c = 1
l = 1k r = 1k (2)	c = 0

This is wrong as right = right.next will persist only locally. To persist it in the next call, make right global or return it.

```
static Node right;
public void reverseDR(Node left, int counter){
    if(left == null){
        return;
    }

    reverseDR(left.next, counter + 1);

    if(counter < size/2){
        swap(left, right);
    }

    right = right.next;
}

public void reverseDR() {
    Node left = head;
    right = head;
    reverseDR(left, 0);
}
```

Dry Run for Data Recursive using Return

if (counter > size(2))

~~l = null~~	r 60 ~~10~~ → 20 → 30 → 40 → 50 → l 10 ~~60~~ → null 1K 2K 3K 4K 5K 6K
~~l = 6k r = 1k~~	→ 60 → r 50 ~~20~~ → 30 → 40 → l 20 ~~50~~ → 10 → null 1K 2K 3K 4K 5K 6K
~~l = 5k r = 1k~~ 2k	60 → r 40 ~~30~~ → l 30 ~~40~~ → 20 → 10 → null 1K 2K 3K 4K 5K 6K
~~l = 4k r = 1k~~ 3k	60 → 50 → 40 → 30 → 20 → 10 → null 1K 2K 3K 4K 5K 6K
~~l = 3k r = 1k~~ 4k	
~~l = 2k r = 1k~~ 5k	
~~l = 1k r = 1k~~ 6k	

Display Reverse

10 → 20 → 30 → 40 → 50 → 60

1k 2k 3k 4k 5k 6k

~~null~~	
~~6k~~	60
~~5k~~	50
~~4k~~	40
~~3k~~	30
~~2k~~	20
~~1k~~	10

print in postorder

```java
private void displayReverseHelper(Node node){
  // write your code here

  if(node == null) {
      return;
  }

  displayReverseHelper(node.next);
  System.out.print(node.data + " ");
}

public void displayReverse(){
  displayReverseHelper(head);
  System.out.println();
}
```

TC = O(N)

Reverse Linked List Pointer Recursive

10 → 20 → 30 → 40 → 50 → 60 → null

1k 2k 3k 4k 5k 6k

10 ⇄ 20 ⇄ 30 ⇄ 40 ⇄ 50 ⇄ 60 ⇄ null

1k 2k 3k 4k 5k 6k

→ After complete recursion 1k's next still points at 2k.

curr	null
curr	6k
curr	5k
curr	4k
curr	3k
curr	2k
curr	1k

→ meri next node hai 6k. uska next mujhe bana do.

node.next.next = node

So we have to swap head & tail first & then set tail's next to null too.

Reverse LL Pointer Recursive Code

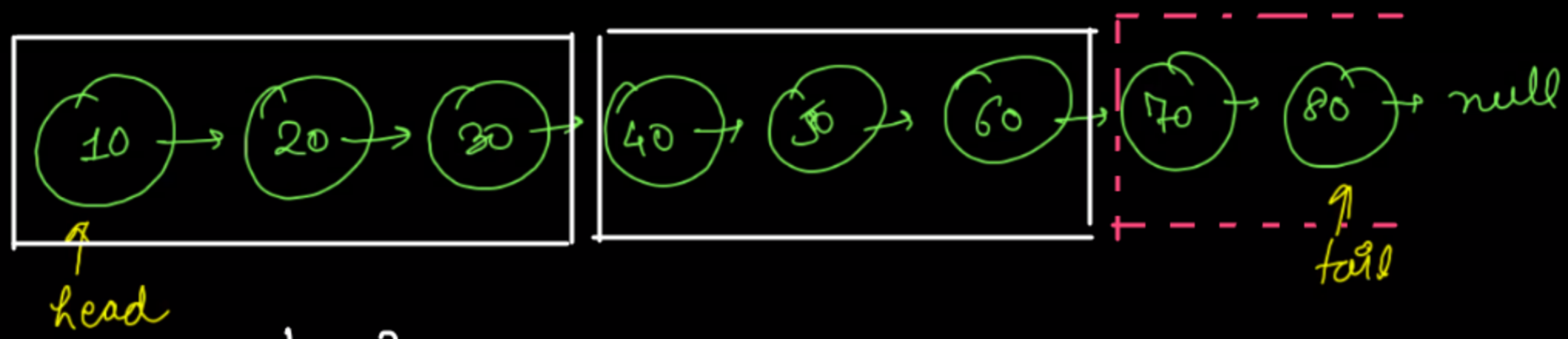
```
private void reversePRHelper(Node node){
  // write your code here

  if(node == null || node.next == null) {
      return;
  }

  reversePRHelper(node.next);

  //khud pe khade hoke apne next ka kaam karao
  node.next.next = node;
}

public void reversePR(){
  // write your code here
  reversePRHelper(head);

  //swap head and tail
  Node temp = head;
  head = tail;
  tail = temp;

  //set tail's next to null
  tail.next = null;
}
}
```

Ye zarooori hai taaki agar head null ho to null pointer exc na aae.

TC = O(N)

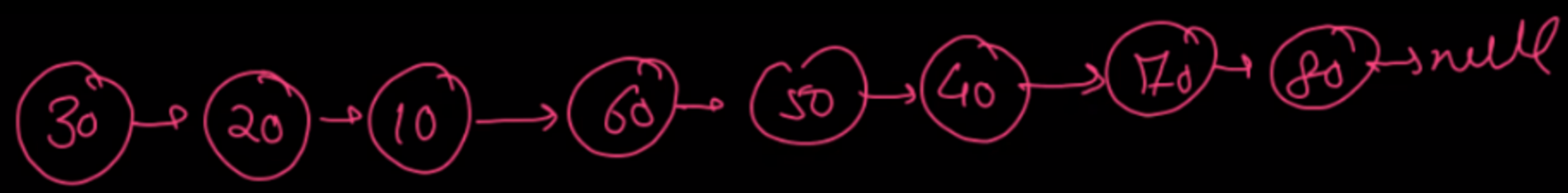
Check for head == null here also to avoid null pointer exception.

K - Reverse in Linked List



$k = 3$

After k Reverse



for each group

→ Remove first from Group

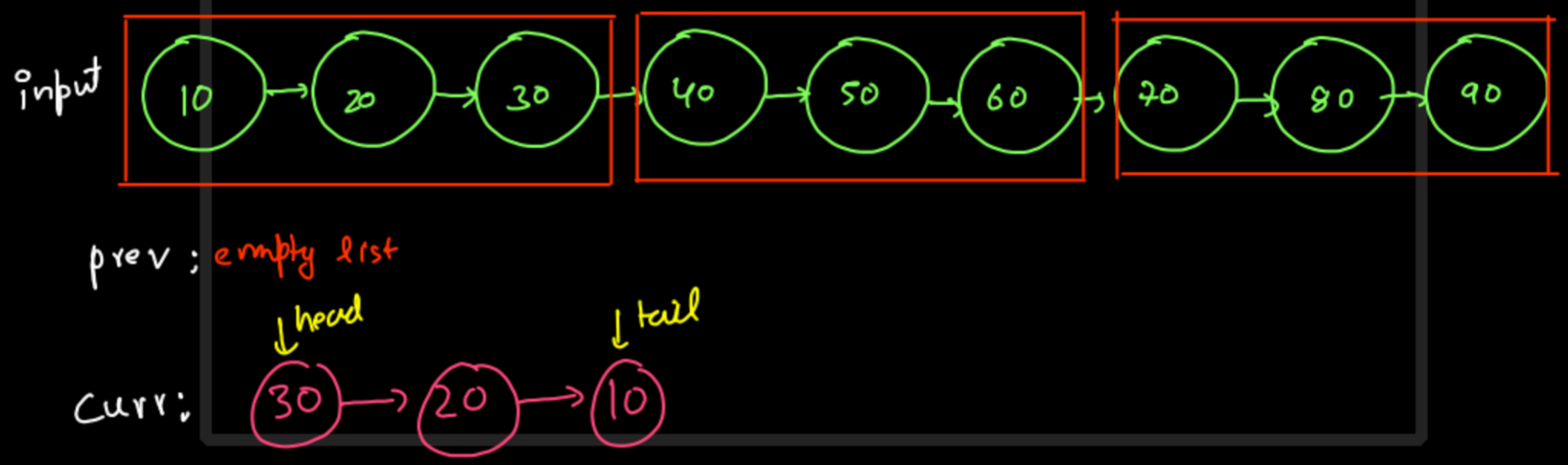
→ Add first to curr LL

Initial state

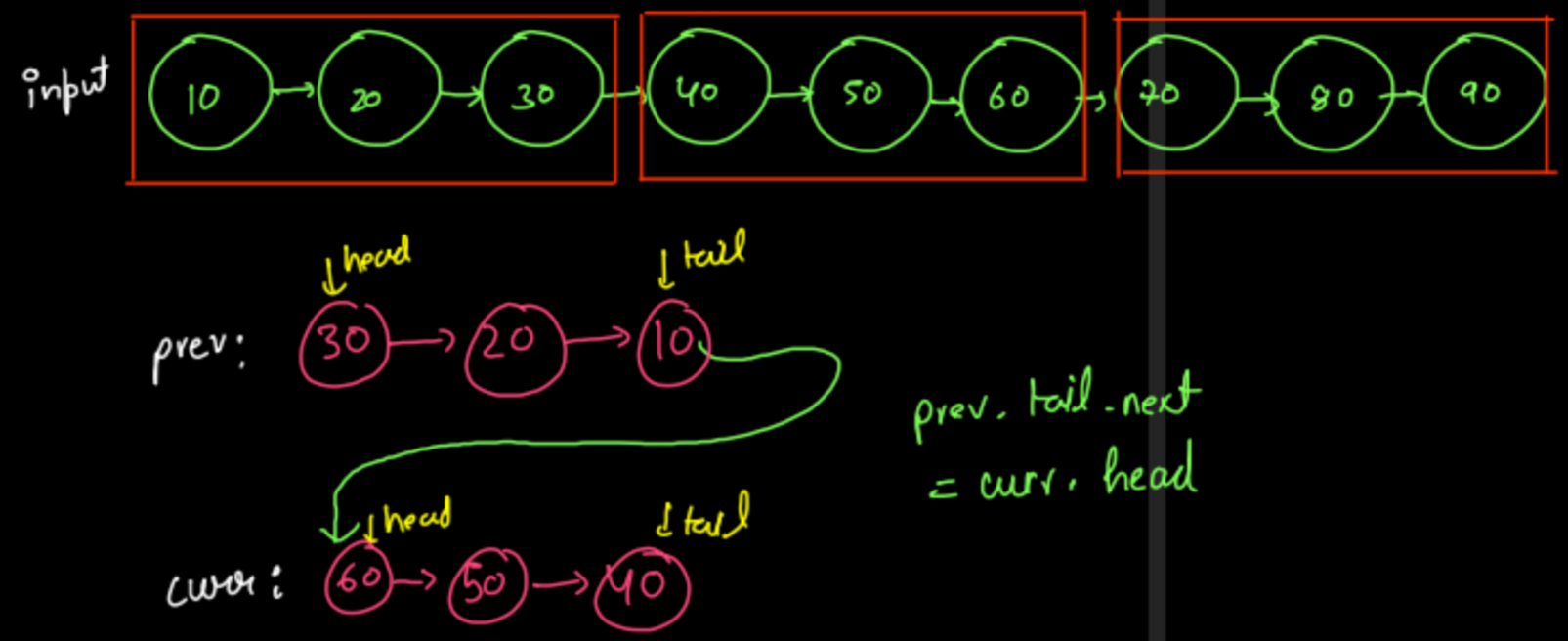
prev : empty list

curr : empty list

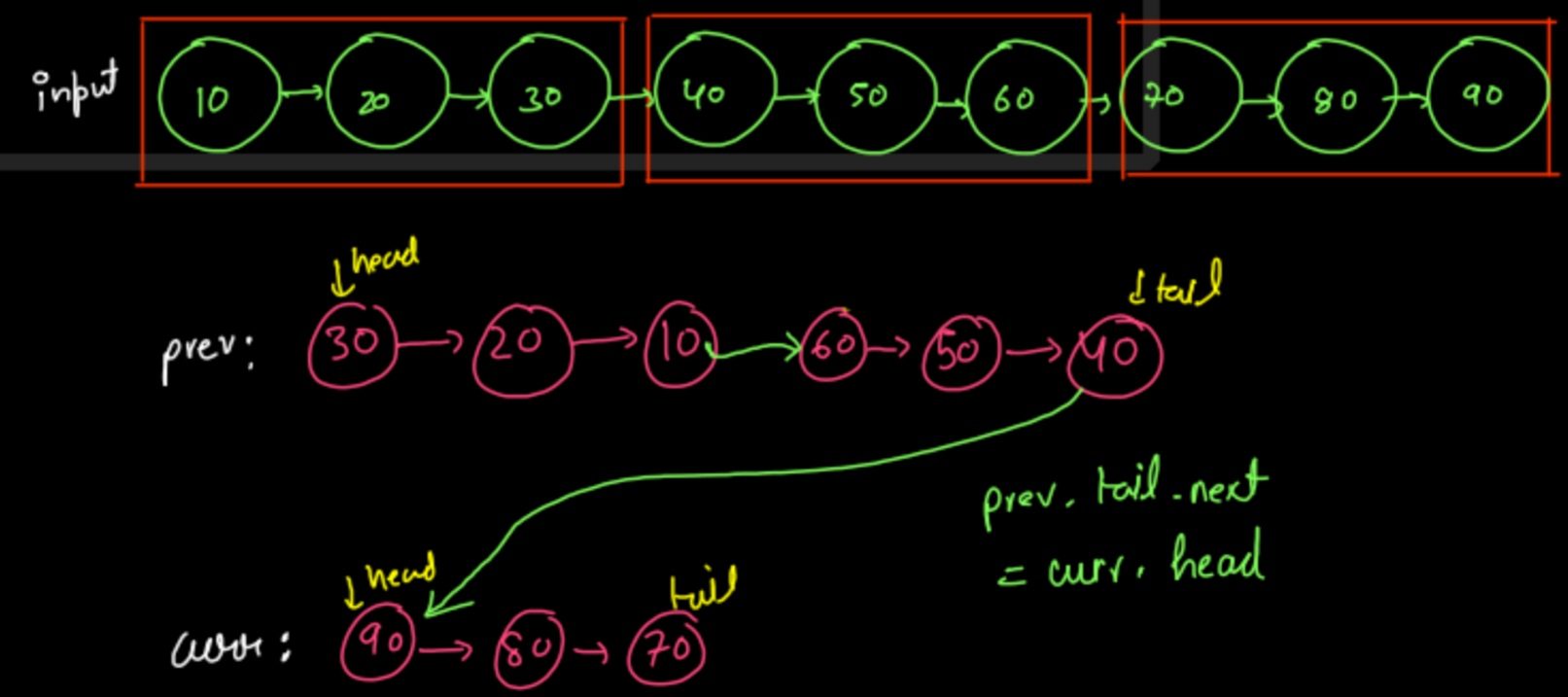
Reversing 1st Group



Reversing 2nd Group



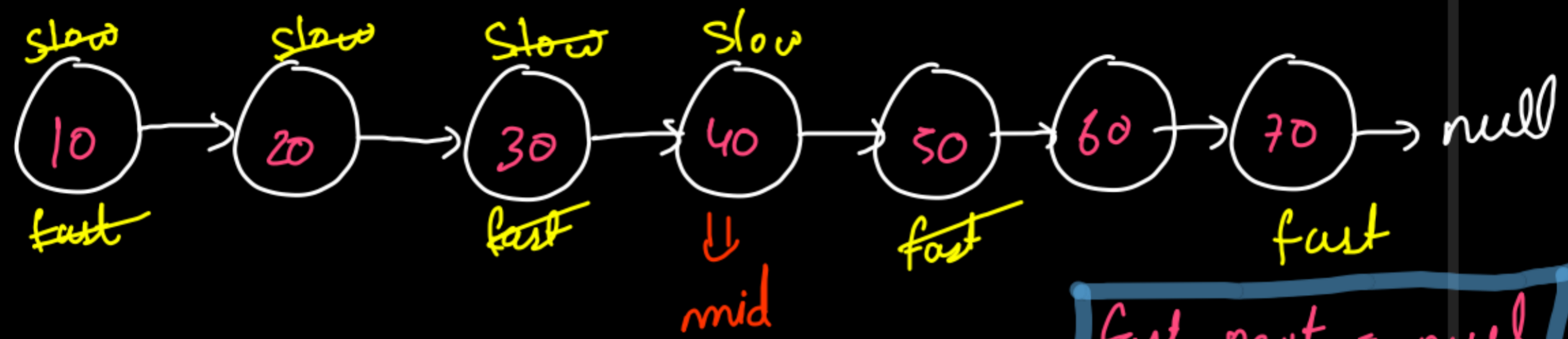
Reversing 3rd Group



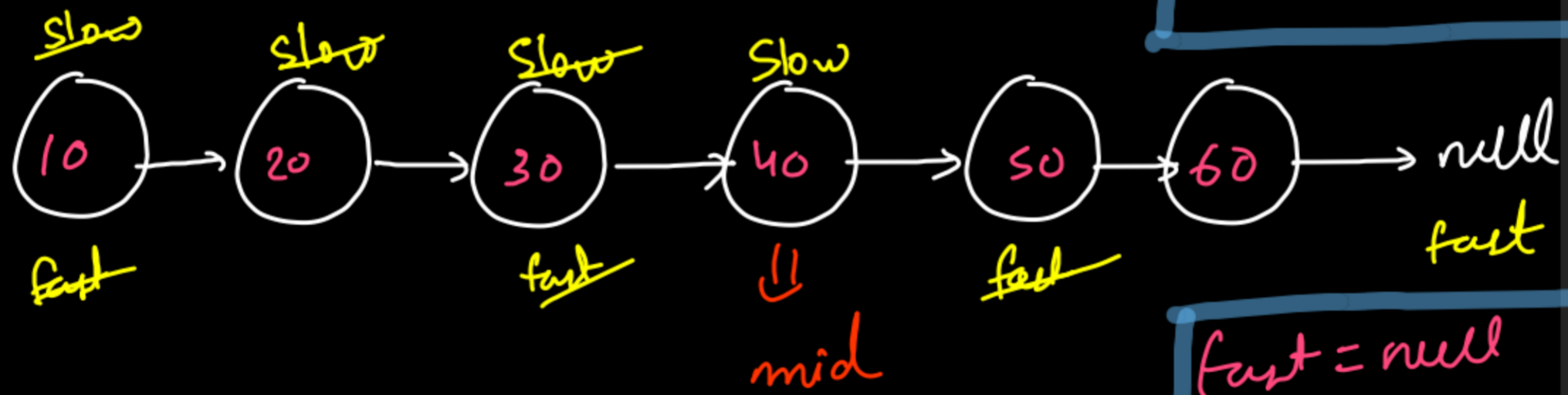
Code for K Reverse

```java
public void kReverse(int k) {
  // write your code here
  LinkedList prev = new LinkedList();

  while(size > 0) {
      LinkedList curr = new LinkedList();

      if(size < k) {
          while(size > 0) {
              int val = head.data;
              this.removeFirst();
              curr.addLast(val);
          }
      }
      else {
          for(int i=0;i<k;i++) {
              int val = head.data;
              this.removeFirst();
              curr.addFirst(val);
          }
      }

      if(prev.head == null) {
          prev = curr;
      } else {
          prev.tail.next = curr.head;
          prev.tail = curr.tail;
          prev.size += curr.size;
      }
  }

  prev.tail.next = null;
  this.head = prev.head;
  this.tail = prev.tail;
  this.size = prev.size;

}
}
```

Mid of Linked List {Hare and Tortoise} {Two Pointers}



fast.next = null
in odd size



fast = null
in even size

Mid of LL Code

```java
class Solution {
    public ListNode middleNode(ListNode head) {

        ListNode slow = head;
        ListNode fast = head;

        while(fast != null && fast.next != null) {
            slow = slow.next;
            fast = fast.next.next;
        }

        return slow;
    }
}
```

$TC = O(N)$

Mathematical Proof

slow

Speed = 1 Node / sec

Time = t

Dist = ? say x

fast

Speed = 2 Nodes / sec

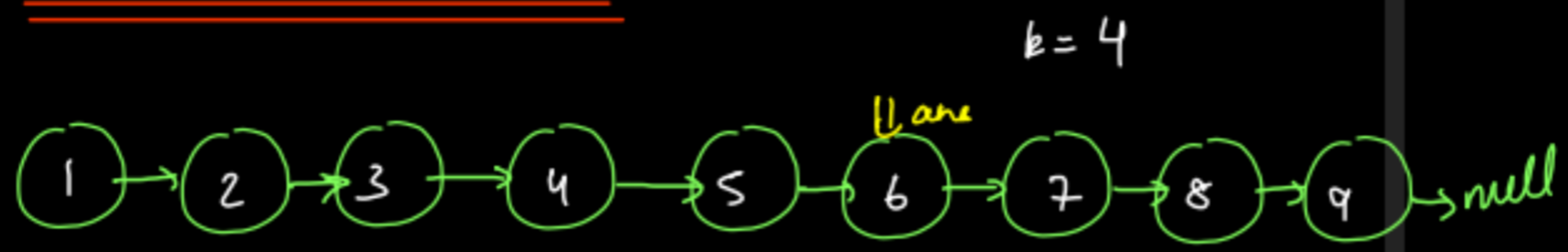
Time = t

Dist = N

$\Rightarrow$ $\text{time} = \frac{\text{Dist}}{\text{speed}}$

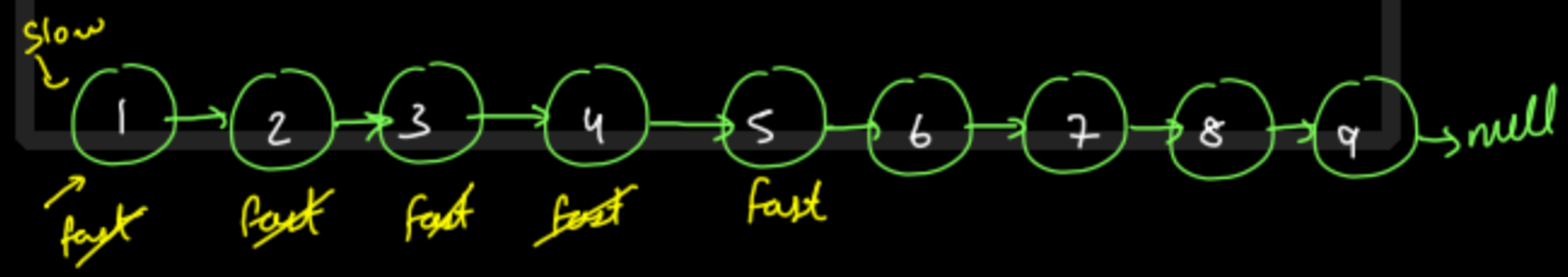
$$\frac{x}{1} = \frac{N}{2} \Rightarrow \boxed{x = \frac{N}{2}}$$

K^{th} Node from End

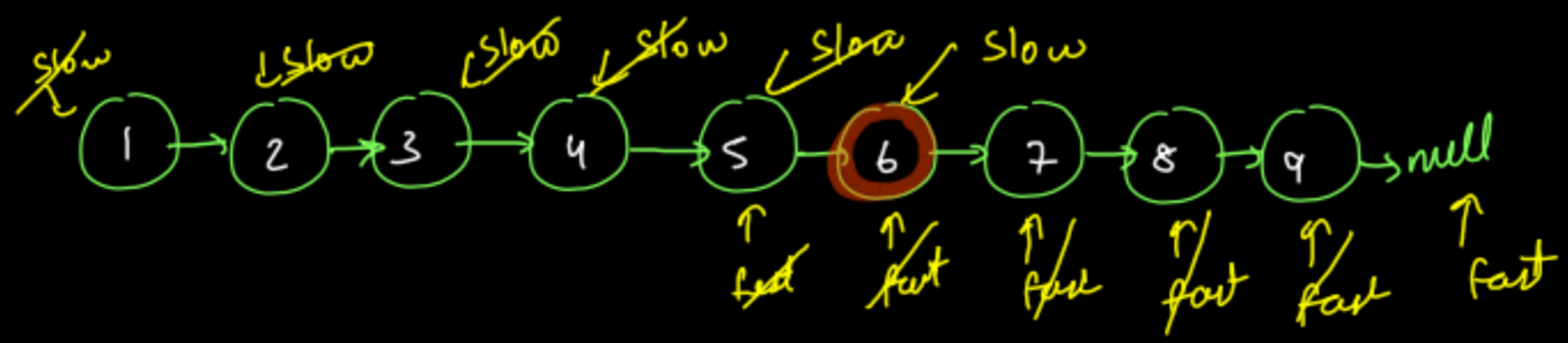


Idea is to have slow at k^{th} node when fast becomes null. To do that, have 2 pointers with some speed but keep some initial distance b/w them.

→ Move fast k times initially



→ Now move slow & fast one step till fast becomes null



K^{th} Node from End Code

```
int getNthFromLast(Node head, int k)
{
     Node slow = head;
    Node fast = head;

    while(fast != null && k-- > 0) {
        fast = fast.next;

    }

    if(k > 0) {
        return -1;
    }

    while(fast != null) {
        slow = slow.next;
        fast = fast.next;

    }

    return slow.data;
}
```

Palindrome List

odd: 1 → 2 → 3 → 4 → 3 → 2 → 1 → null (T)

Even: 1 → 2 → 3 → 4 → 4 → 3 → 2 → 1 → null (T)

1 → 2 → 3 → 4 → 4 → 5 → 2 → 1 → null (f)

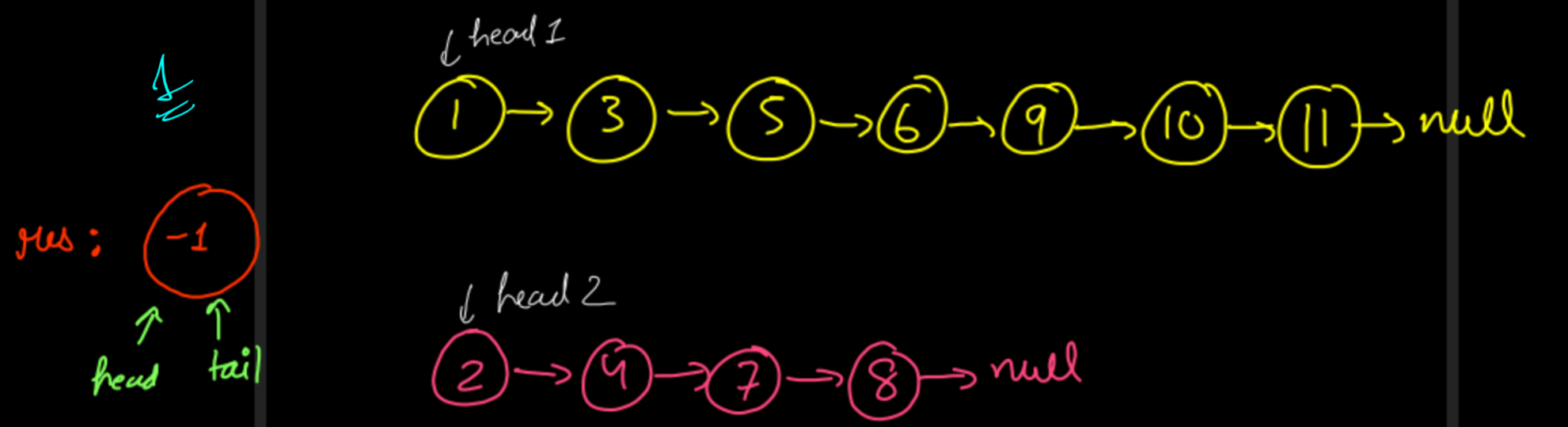
Approach:

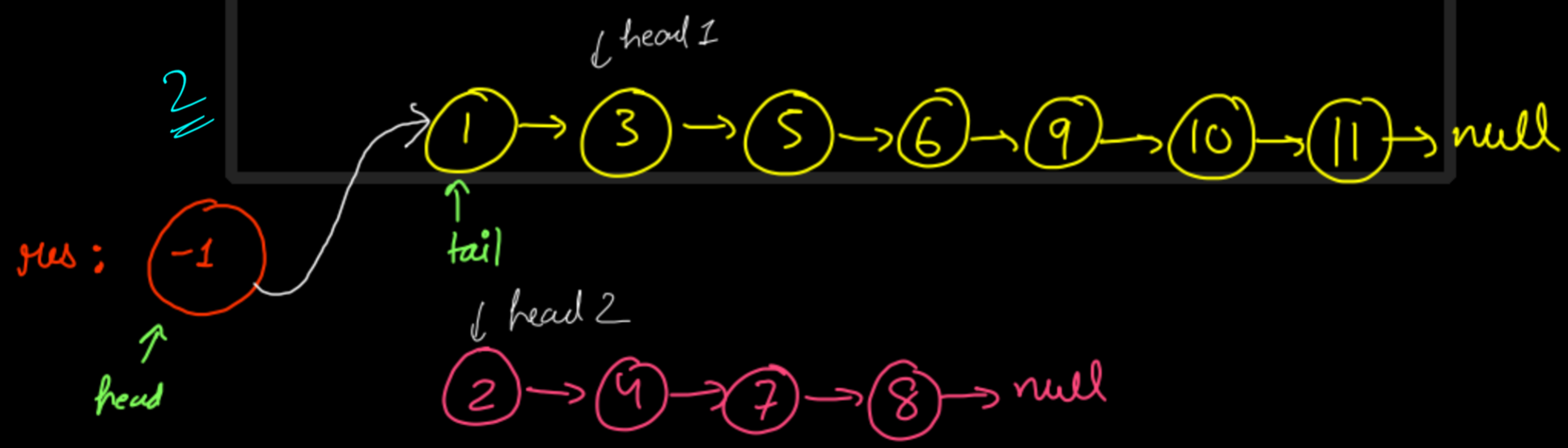
1. Find middle node
2. Reverse the second part
3. Compare both the parts
   - equal → Yes (Palindrome)
   - not equal → No

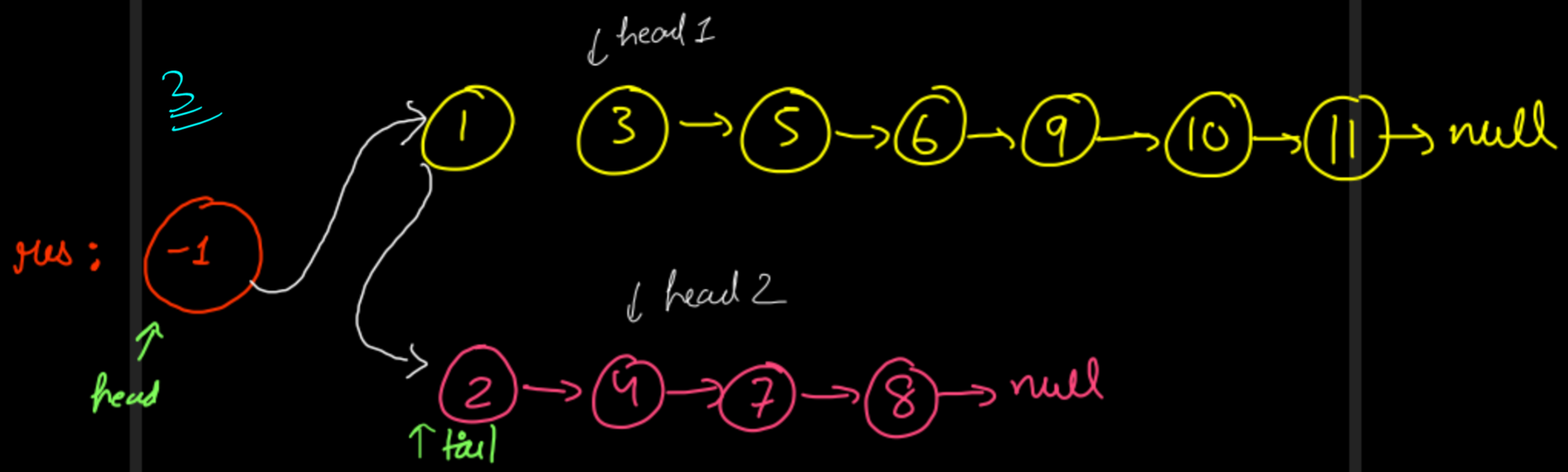
```java
public ListNode reverse(ListNode head){
    ListNode prev = null, curr = head;
    while(curr != null){
        ListNode ahead = curr.next;
        curr.next = prev;
        prev = curr;
        curr = ahead;
    }
    return prev;
}

public ListNode middle(ListNode head){
    ListNode slow = head, fast = head;
    ListNode prev = null;

    while(fast != null && fast.next != null){
        prev = slow;
        slow = slow.next;
        fast = fast.next.next;
    }

    if(fast == null) // even
        return prev;
    return slow;
}
```

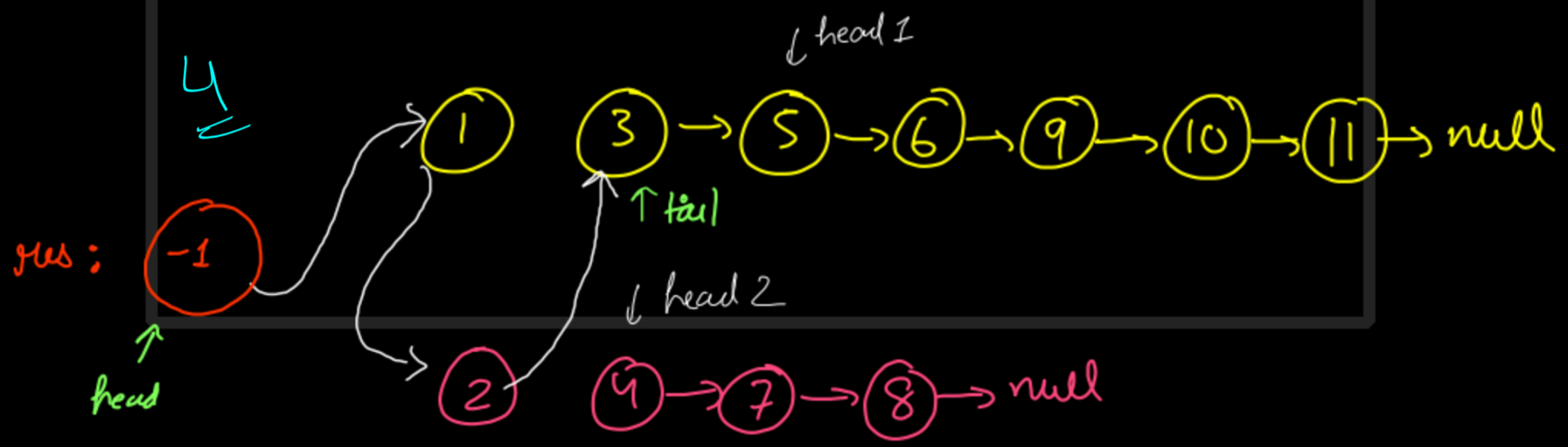
```java
public boolean isPalindrome(ListNode head) {
    if(head == null || head.next == null){
        return true;
    }

    ListNode mid = middle(head);
    ListNode second = reverse(mid.next);

    while(head != null && second != null){
        if(head.val != second.val) return false;
        head = head.next;
        second = second.next;
    }
    return true;
}
```

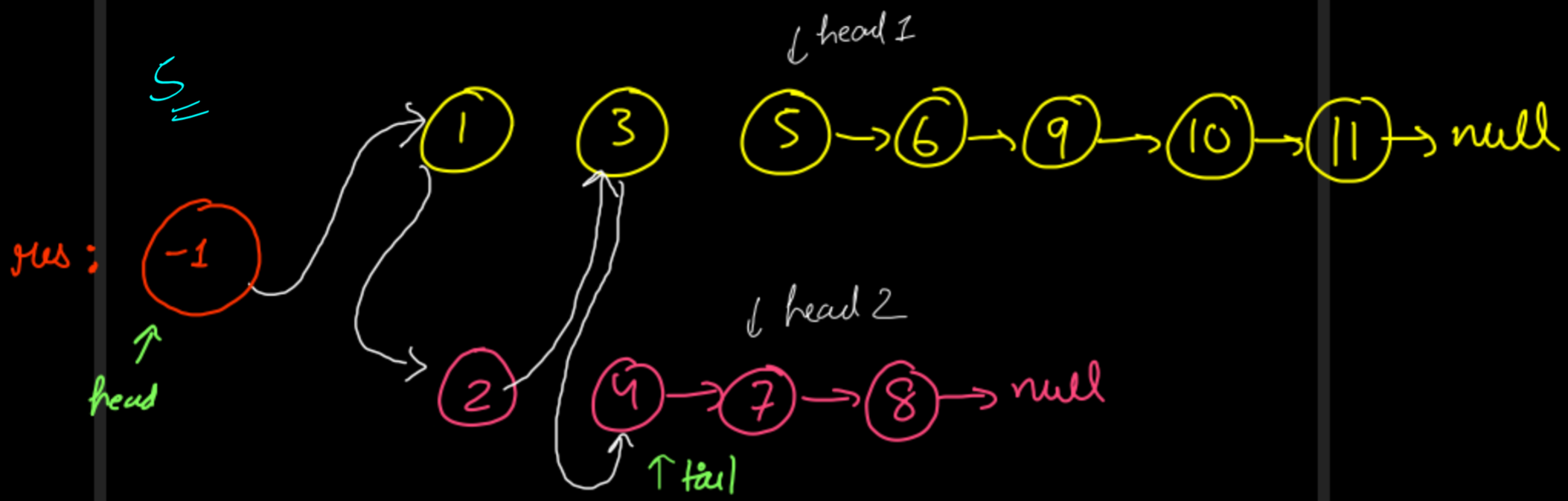
Merge 2 sorted LL

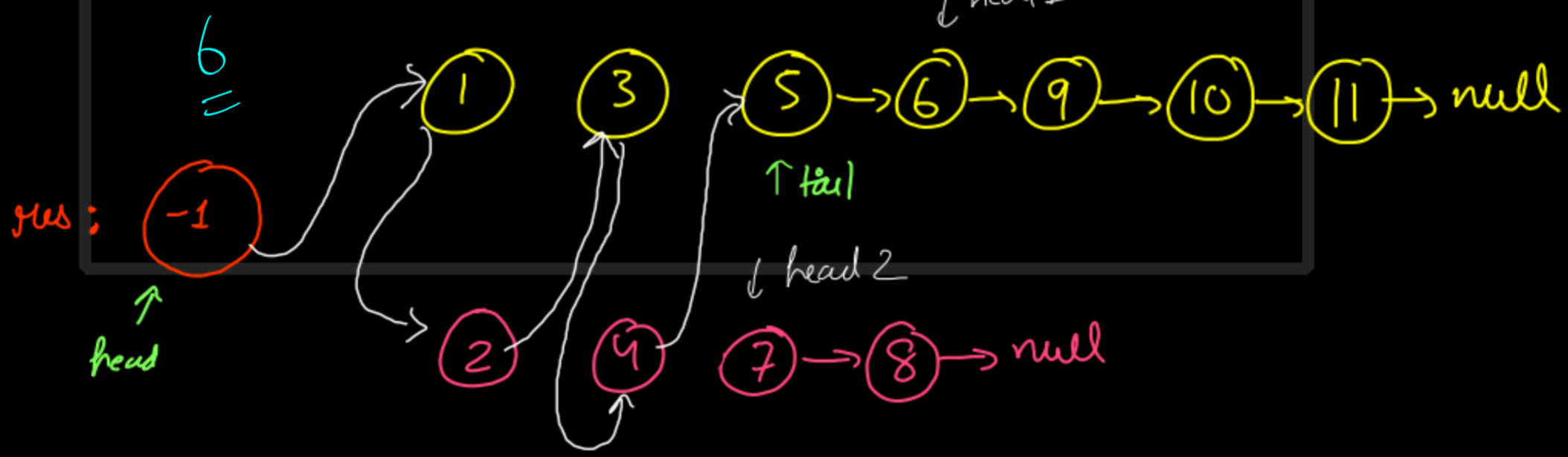


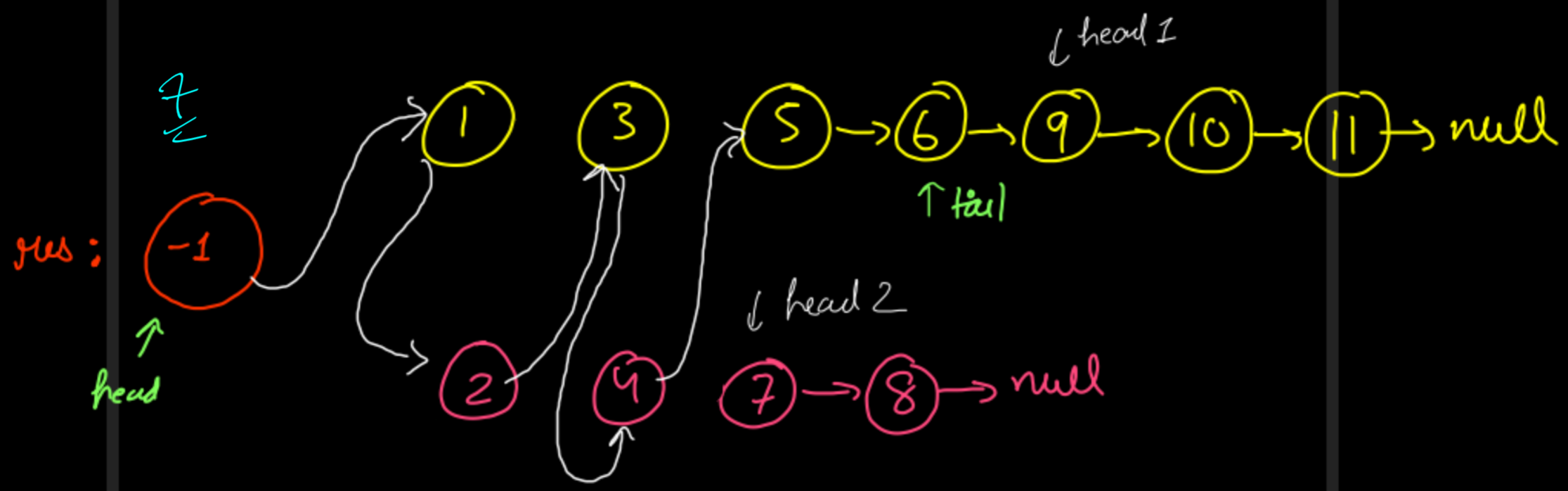


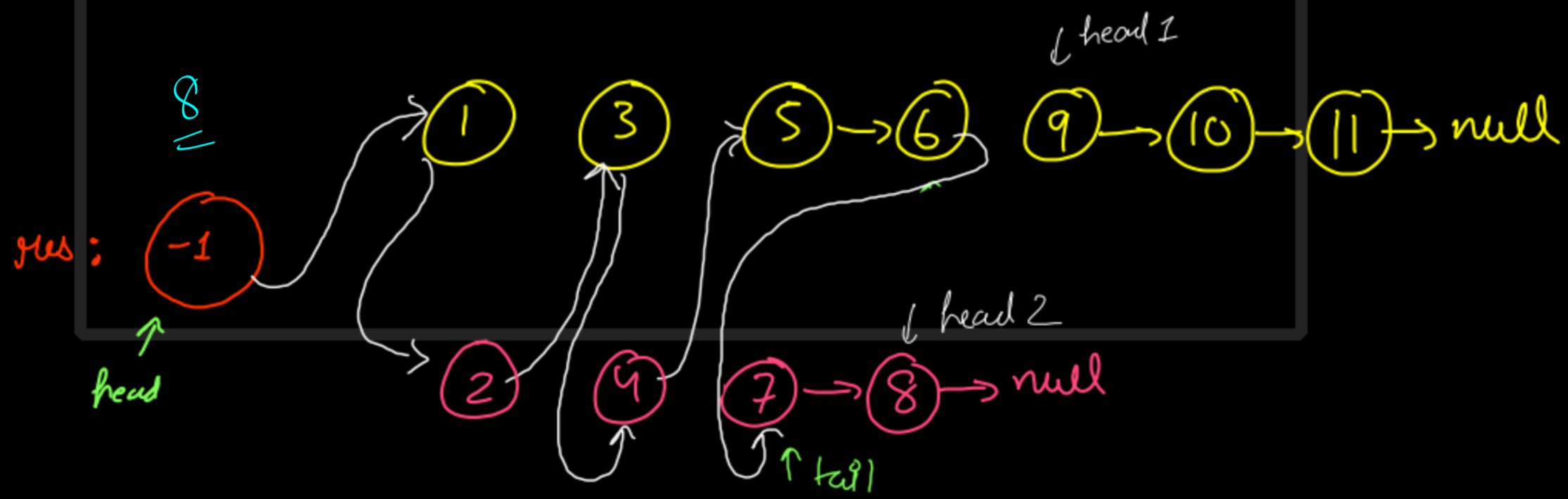

3
head 1
1
3 → 5 → 6 → 9 → 10 → 11 → null
res :
-1
head 2
2 → 4 → 7 → 8 → null
head
tail

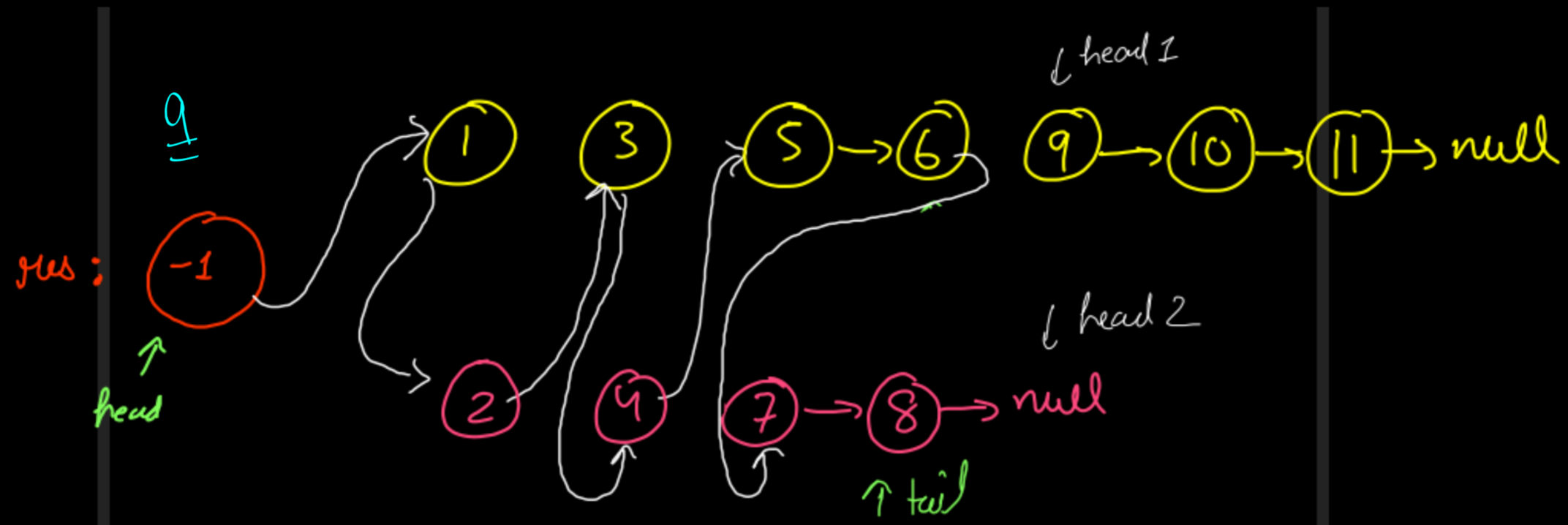

4
head 1
1
3 → 5 → 6 → 9 → 10 → 11 → null
tail
res :
-1
head 2
2
4 → 7 → 8 → null
head

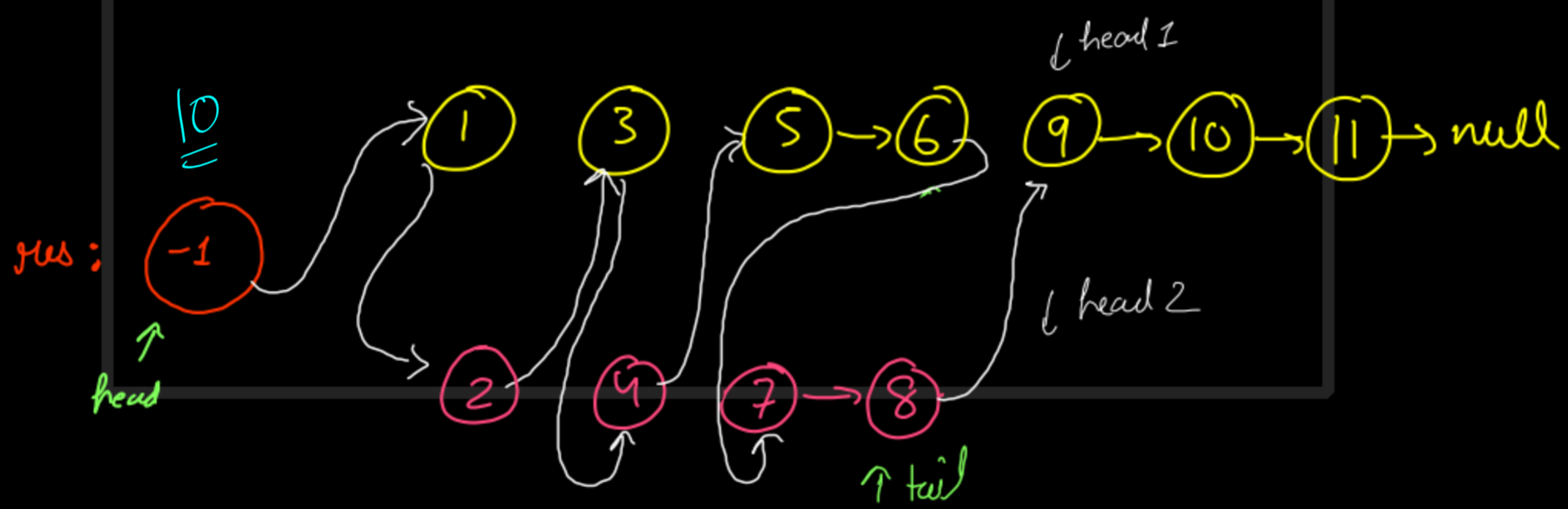

5
head 1
1
3
5
6
9
10
11
null
res :
-1
head
head 2
2
4
7
8
null
tail


6
head 1
1
3
5
6
9
10
11
null
tail
res :
-1
head
head 2
2
4
7
8
null

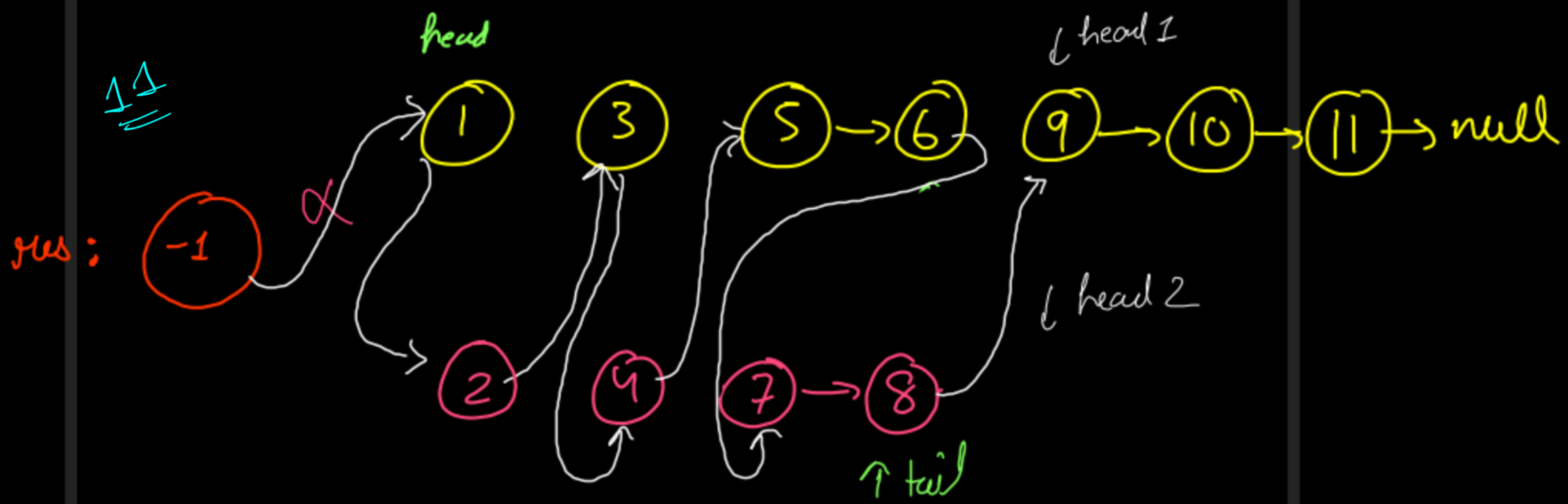

7
res :
-1
head
1
3
5
6
9
10
11
null
head 1
tail
2
4
7
8
null
head 2


8
res :
-1
head
1
3
5
6
9
10
11
null
head 1
2
4
7
8
null
head 2
tail

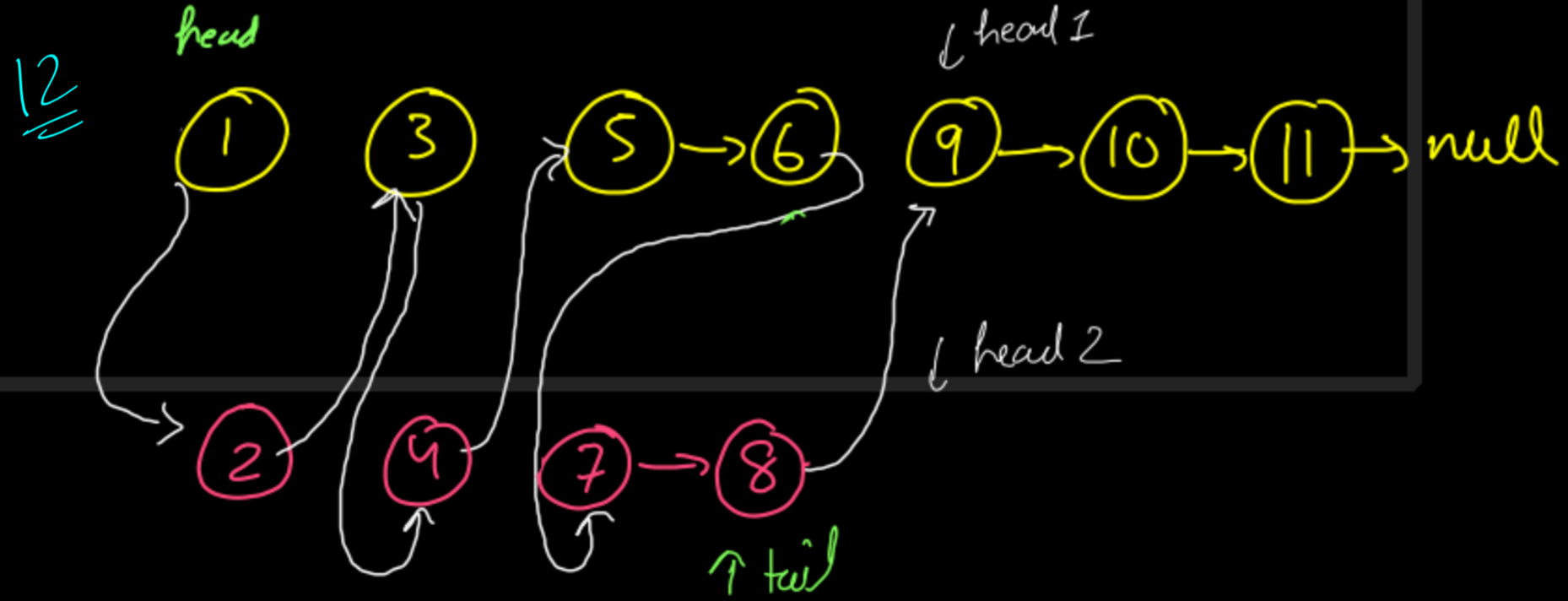

9
res :
-1
head
1
3
5
6
9
10
11
null
head 1
2
4
7
8
null
tail
head 2


10
res :
-1
head
1
3
5
6
9
10
11
null
head 1
2
4
7
8
tail
head 2

11


head
head 1
res :
-1
1
3
5
6
9
10
11
null
2
4
7
8
head 2
tail

12


head
head 1
1
3
5
6
9
10
11
null
head 2
2
4
7
8
tail

Merge 2 Sorted Lists Code (GfG)

```
Node sortedMerge(Node head1, Node head2) {
    Node dummy = new Node(-1);
    Node head = dummy, tail = dummy;

    while(head1 != null && head2 != null) {
        if(head1.data < head2.data) {
            tail.next = head1;
            head1 = head1.next;
        } else {
            tail.next = head2;
            head2 = head2.next;
        }

        tail = tail.next;
    }

    if(head1 != null) tail.next = head1;
    else tail.next = head2;

    return dummy.next;
}
```

→ to remove dummy node.

Merge 2 Sorted Lists (Leetcode)

```java
public ListNode mergeTwoLists(ListNode head1, ListNode head2) {
    ListNode dummy = new ListNode(-1);
    ListNode head = dummy, tail = dummy;

    while(head1 != null && head2 != null) {
        if(head1.val < head2.val) {
            tail.next = head1;
            head1 = head1.next;
        } else {
            tail.next = head2;
            head2 = head2.next;
        }

        tail = tail.next;
    }

    if(head1 != null) tail.next = head1;
    else tail.next = head2;

    return dummy.next;
}
```

Merge K Sorted Linked Lists (Leetcode Hard)

n $1 \to 4 \to 7$

n $3 \to 6 \to 9$

n $2 \to 5 \to 10$

n $1 \to 6 \to 10$

$N = n * k$

to find min ⇒ k elements
O(k) time

$TC = O(\underset{\downarrow}{N} * k)$

$TC = O(nk^2)$

Same approach as prev

$1 \to 1 \to 2 \to 3 \to 4 \to 5 \to 6 \to 6 \to 7 \to 9 \to 10 \to 10$

Code for Merge K Sorted Lists

```java
public int minNode(ListNode[] lists) {
    int min = Integer.MAX_VALUE;
    int idx = -1;
    for(int i=0;i<lists.length;i++) {
        if(lists[i] != null && lists[i].val < min) {
            idx = i;
            min = lists[i].val;
        }
    }

    return idx;
}
```

```java
public ListNode mergeKLists(ListNode[] lists) {

    if(lists.length == 0) {
        return null;
    }

    ListNode dummy = new ListNode(-1);
    ListNode head = dummy, tail = dummy;

    while(true) {
        int minIdx = minNode(lists);
        if(minIdx == -1) break;
        tail.next = lists[minIdx];
        lists[minIdx] = lists[minIdx].next;
        tail = tail.next;
    }

    return dummy.next;
}
```

Constraints:

- `k == lists.length`
- `0 <= k <= 10^4`
- `0 <= lists[i].length <= 500`
- `-10^4 <= lists[i][j] <= 10^4`
- `lists[i]` is sorted in ~~ascending order~~.
- The sum of `lists[i].length` won't exceed `10^4`.

$\Downarrow$

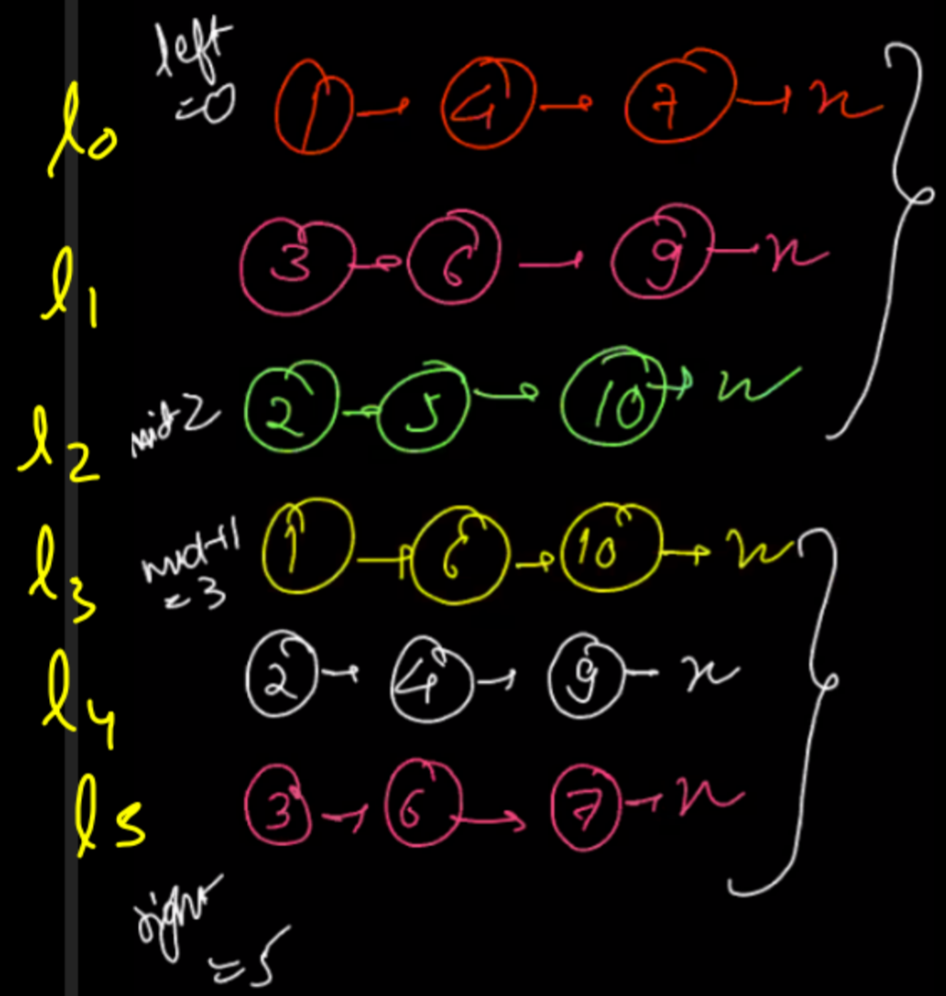
This constraint means that capital N will not exceed 10^4 & TC = N * k

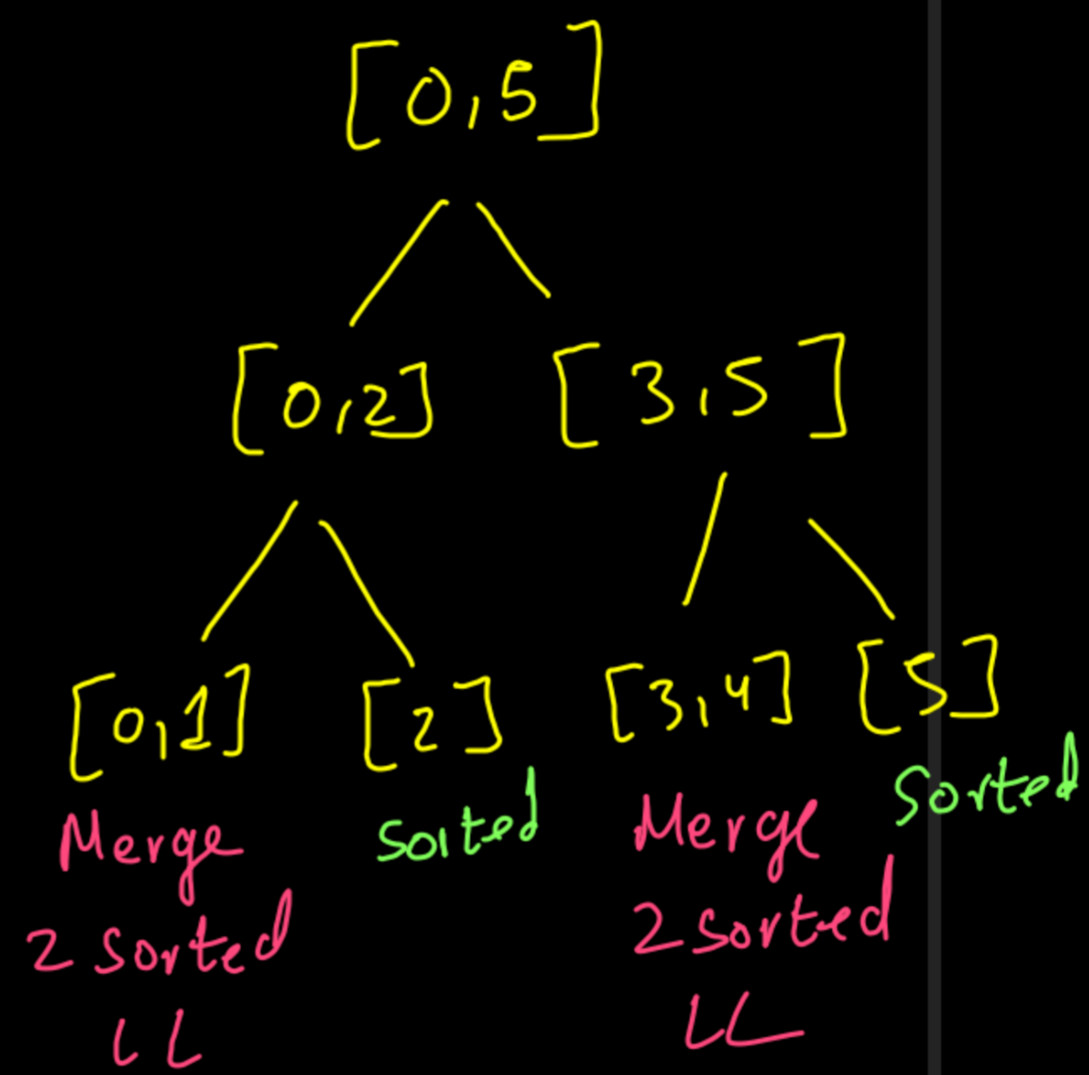
$\Rightarrow$ TC = $10^4 * 10^4 = 10^8$ (Hence our brute force solution worked)

** Use priority queue for comparing nodes instead of loop.

& implement comparator as we will make PQueue of List Nodes

Best optimized Approach {Divide & Conquer}





Code Using Divide & Conquer

```java
public ListNode mergeKLists(ListNode[] lists) {
    return mergeKLists(lists,0,lists.length-1);
}

public ListNode mergeKLists(ListNode[] lists,int lo, int hi) {

    if(lo > hi) {
        return null;
    }

    if(lo == hi) {
        return lists[lo];
    }

    int mid = lo + (hi-lo)/2;
    ListNode leftHalf = mergeKLists(lists,lo,mid);
    ListNode rightHalf = mergeKLists(lists,mid + 1,hi);

    return mergeTwoLists(leftHalf,rightHalf);
}
```

```java
public ListNode mergeTwoLists(ListNode head1, ListNode head2) {
    ListNode dummy = new ListNode(-1);
    ListNode head = dummy, tail = dummy;

    while(head1 != null && head2 != null) {
       if(head1.val < head2.val) {
           tail.next = head1;
           head1 = head1.next;
       } else {
           tail.next = head2;
           head2 = head2.next;
       }

       tail = tail.next;
    }

    if(head1 != null) tail.next = head1;
    else tail.next = head2;

    return dummy.next;
}
```

Time Complexity (Divide & Conq)

$$T(k) = 2T(k/2) + \frac{k}{2} * n$$

$$2\,T(k/2) = \left(2T(k/4) + \frac{k}{4} * n\right) 2$$

$$\vdots$$

$$T(1) = 2T(0) + \frac{k}{2} * n$$

$$T(K) = kT(0) + k * n * \log_2 k$$

$$\boxed{TC = O(nk\log_2 k)}$$

Codes for Merge Sort a LL

```java
public ListNode sortList(ListNode head) {
    return helper(head);
}

public ListNode helper(ListNode head) {

    if(head == null || head.next == null) {
        return head;
    }

    ListNode mid = getMiddle(head);
    ListNode list2 = mid.next;
    mid.next = null;

    ListNode list1 = head;

    ListNode leftSortedList = helper(list1);
    ListNode rightSortedList = helper(list2);

  return  mergeTwoLists(leftSortedList, rightSortedList);
}
```

```java
pub

}

publ
```

```java
public ListNode getMiddle(ListNode head) {
    ListNode slow = head;
    ListNode fast = head;
    ListNode prev = null;

    while(fast != null && fast.next != null) {
        prev = slow;
        slow = slow.next;
        fast = fast.next.next;
    }

    if(fast == null) return prev; //this is even case
    return slow;
}
```

```java
public ListNode mergeTwoLists(ListNode head1, ListNode head2) {
    ListNode dummy = new ListNode(-1);
    ListNode head = dummy, tail = dummy;

    while(head1 != null && head2 != null) {
       if(head1.val < head2.val) {
           tail.next = head1;
           head1 = head1.next;
       } else {
           tail.next = head2;
           head2 = head2.next;
       }

       tail = tail.next;
    }

    if(head1 != null) tail.next = head1;
    else tail.next = head2;

    return dummy.next;
}
```

Why merge sort is preferred for linked list
and quick sort is preferred for arrays.

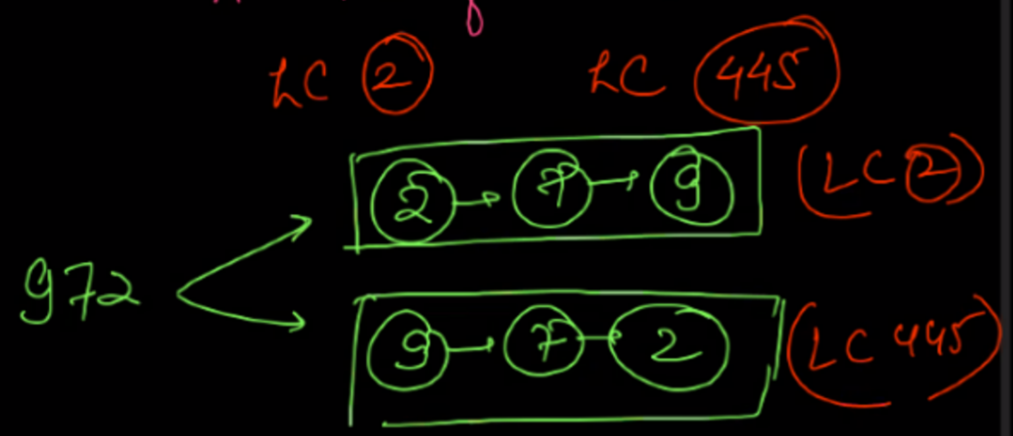
merge sort on LL

- $T(N) \rightarrow O(n \log n)$
- space $\rightarrow$ inplace

However Recursion call stack space is $O(\log_2 N)$

Add 2 Linked Lists

Addition of 2 LL



boost library C++

java has big Integer library

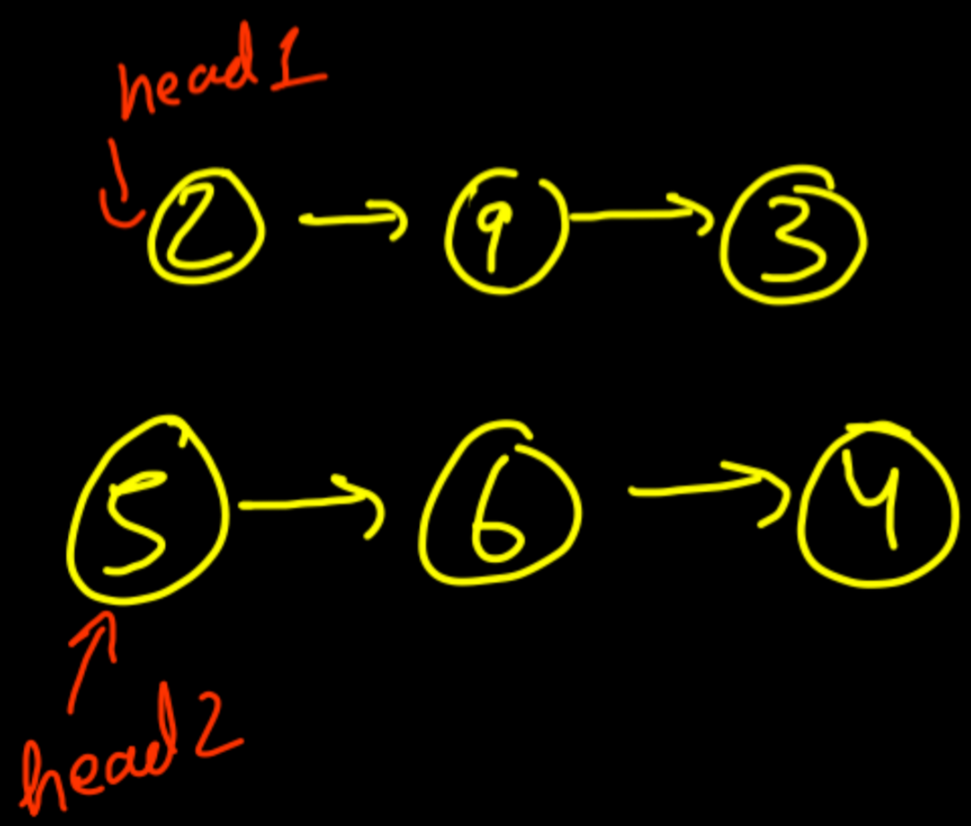
Python handles big integers easily by internally implementing LL.

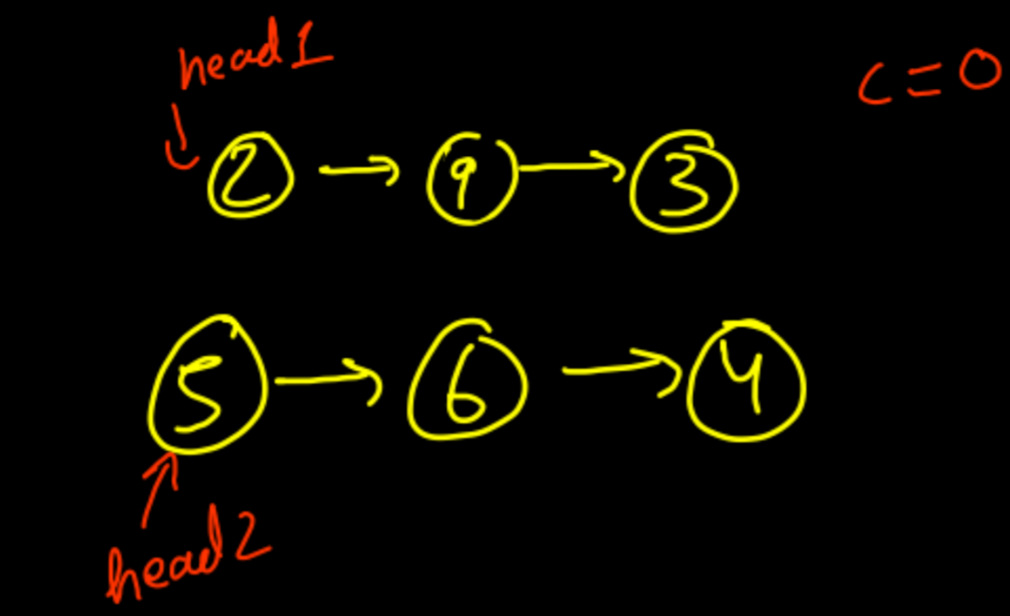
Leetcode Ques 2

No = 342 LL: 2 → 4 → 3

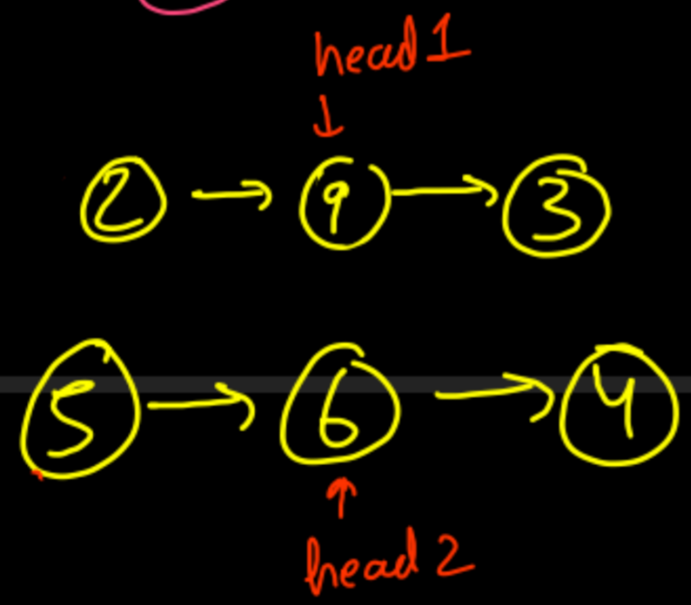
No = 465 LL: 5 → 6 → 4

c = 0





res: 7 & c=0



9+6+0=15 %10=5

res: 7 → 5 & c = 15/10 = 1

head1

$c = 0$

$2 \rightarrow 9 \rightarrow 3$

$5 \rightarrow 6 \rightarrow 4$

head2

$3 + 4 + 1 = 8$

res: $7 \rightarrow 5 \rightarrow 8$ & $ca = 0$

if one LL becomes empty, work will continue. {same as in add^n of arrays}

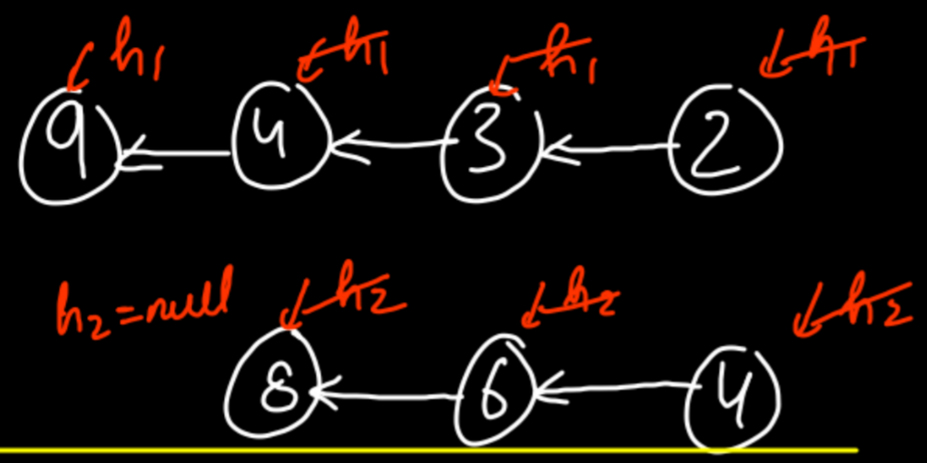
Leetcode : 2 (Solution code)

```java
public ListNode addTwoNumbers(ListNode l1, ListNode l2) {

    ListNode dummy = new ListNode(-1);
    ListNode head = dummy, tail = dummy;
    int carry = 0;

    while(l1 != null || l2 != null || carry > 0) {
        int d1 = (l1 == null) ? 0 : l1.val;
        int d2 = (l2 == null) ? 0 : l2.val;

        ListNode temp = new ListNode((d1 + d2 + carry) % 10);
        carry = (d1 + d2 + carry) / 10;

        tail.next = temp;
        tail = temp;

        if(l1 != null) l1 = l1.next;
        if(l2 != null) l2 = l2.next;
    }

    return dummy.next;
}
```

Leetcode : 445 Solution

```java
public ListNode addTwoNumbers(ListNode l1, ListNode l2) {
    l1 = reverse(l1);
    l2 = reverse(l2);
    ListNode dummy = new ListNode(-1);
    ListNode head = dummy, tail = dummy;
    int carry = 0;

    while(l1 != null || l2 != null || carry > 0) {
        int d1 = (l1 == null) ? 0 : l1.val;
        int d2 = (l2 == null) ? 0 : l2.val;

        ListNode temp = new ListNode((d1 + d2 + carry) % 10);
        carry = (d1 + d2 + carry) / 10;

        tail.next = temp;
        tail = temp;

        if(l1 != null) l1 = l1.next;
        if(l2 != null) l2 = l2.next;
    }

    return reverse(dummy.next);
}
```

Subtraction in Linked List



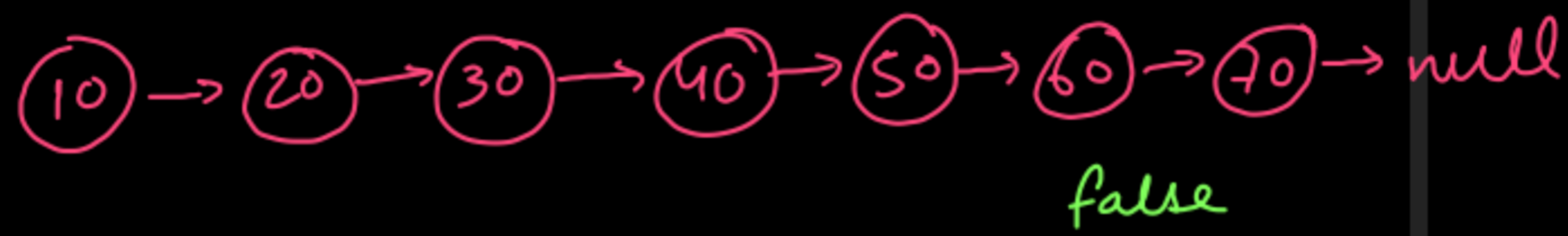
borrow = ~~0~~ = ~~1~~
−1

while(h1 != null)

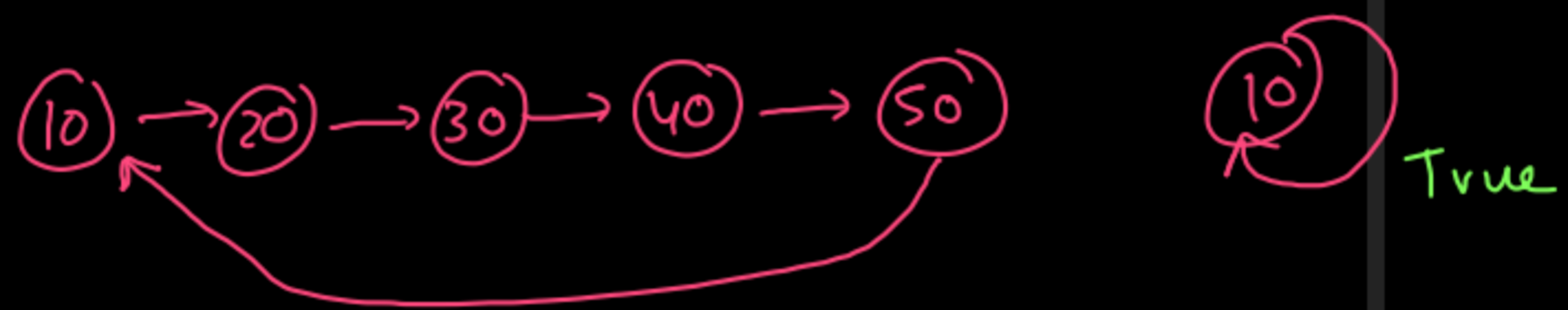
Code in HW

Floyd's Cycle Detection (LC 141)

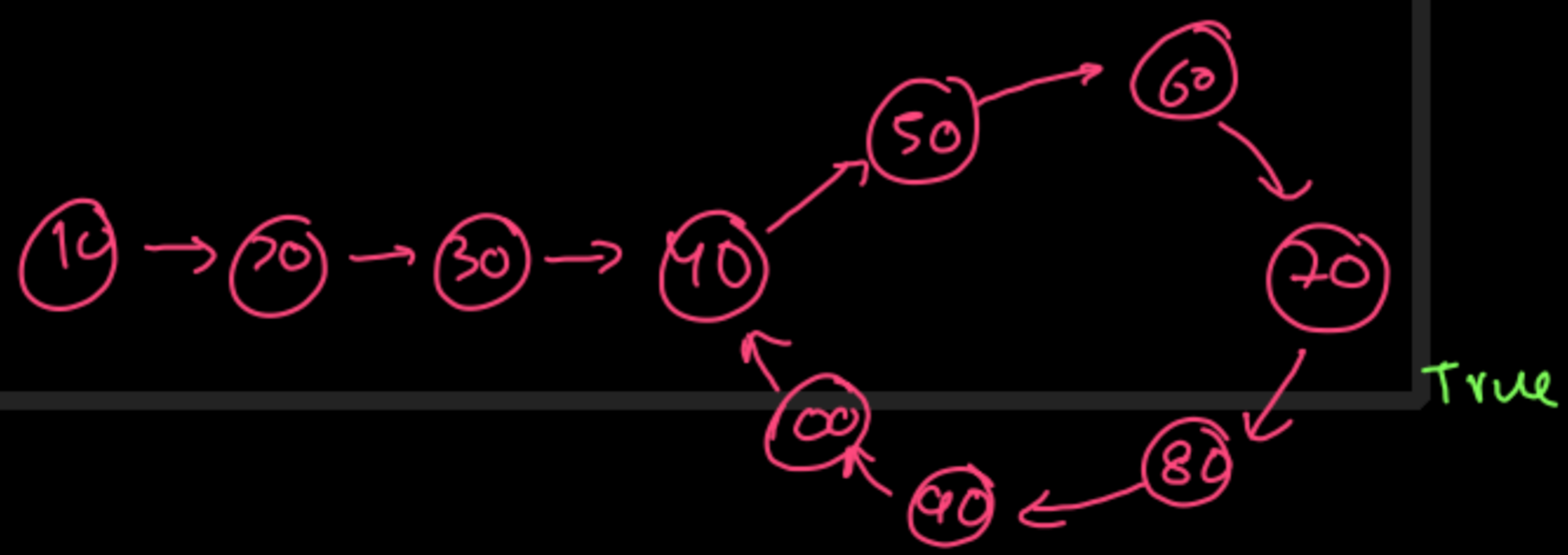
Case 1
SLL



Case 2
CSLL



Case 3
SLL
+ Loop

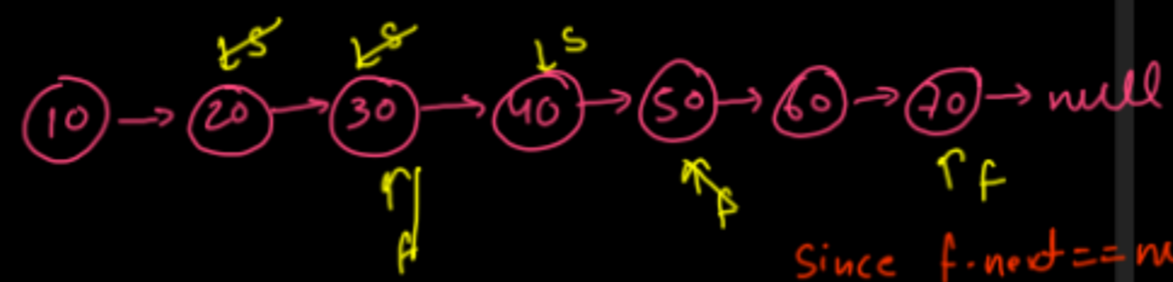


First Approach

Store the traversed nodes in a HashMap or HashSet & if the node is visited again, cycle is detected

Floyd's Cycle Detection (Two Pointer)

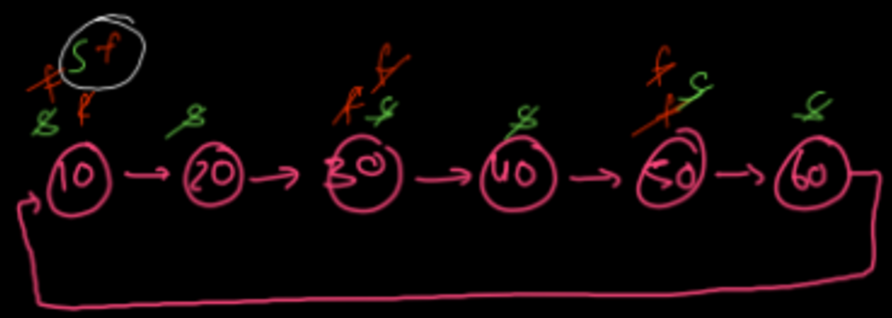
Case 1



Since f.next == null
No LOOP detected

Case: 2

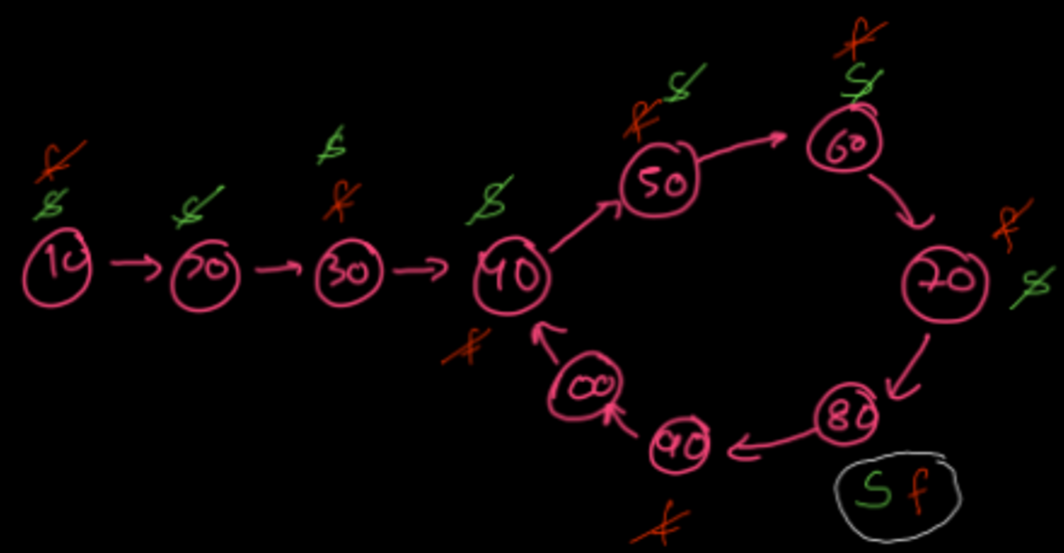
CLL



Since fast & slow meet
a cycle is detected.

Case 3

SLL
+ Loop



Since slow & fast meet again
a loop is detected

Corner Case:

Again, slow & fast meet again

Corner Case ask to interviewer

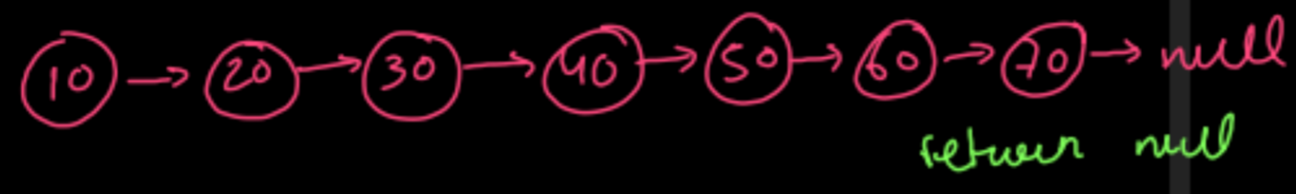
if (head == null) -> return true or false

Code for floyds' Cycle Detection

```java
public boolean hasCycle(ListNode head) {
    if(head == null || head.next == null) return false;

    ListNode slow = head;
    ListNode fast = head;

    while(fast!=null && fast.next!=null) {
        slow = slow.next;
        fast = fast.next.next;

        if(slow == fast) return true;
    }

    return false;
}
```

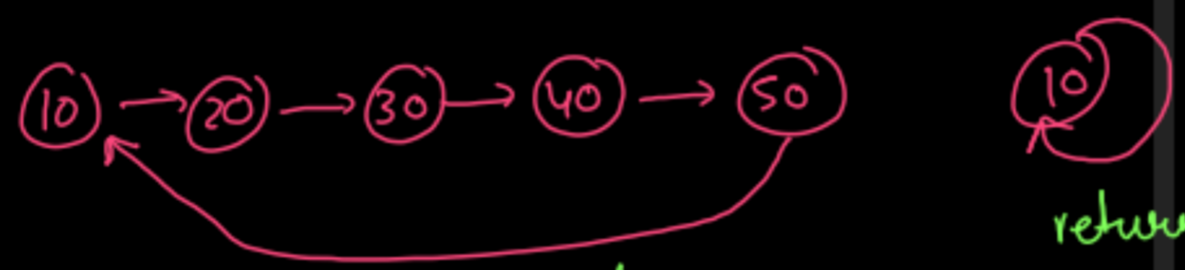
Starting Point of Loop (LC142)

Case 1
SLL



return null

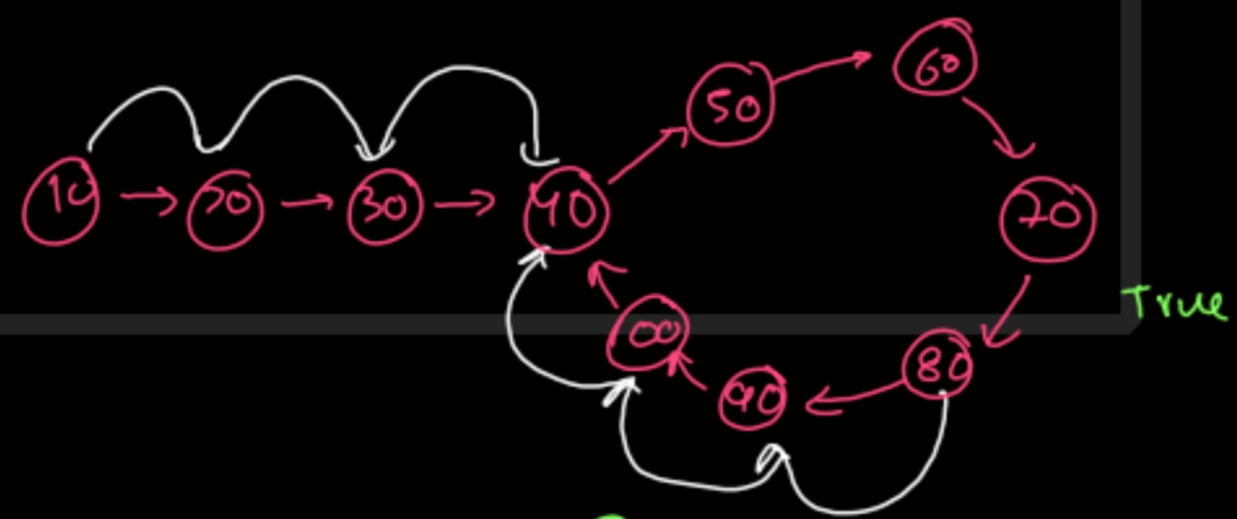
Case 2
CSLL



return 10 head

return 10 head

Case 3
SLL
+ Loop

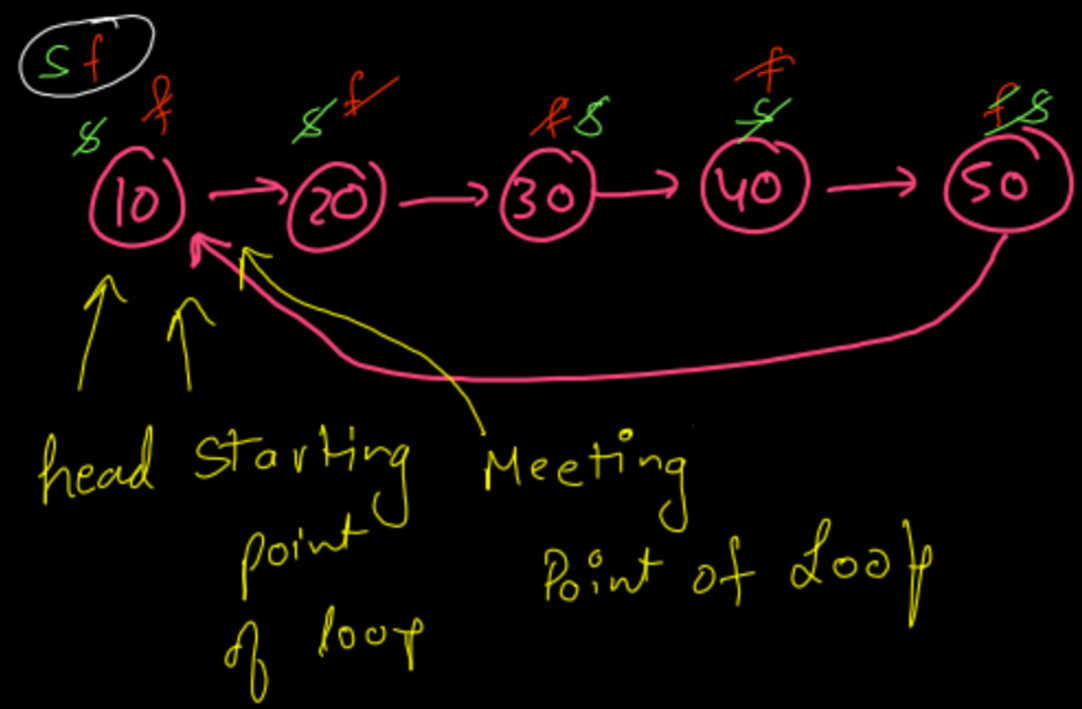


return 80

* Starting point of the loop is at the same distance from meeting point & head {we will use this obs}

Case 2

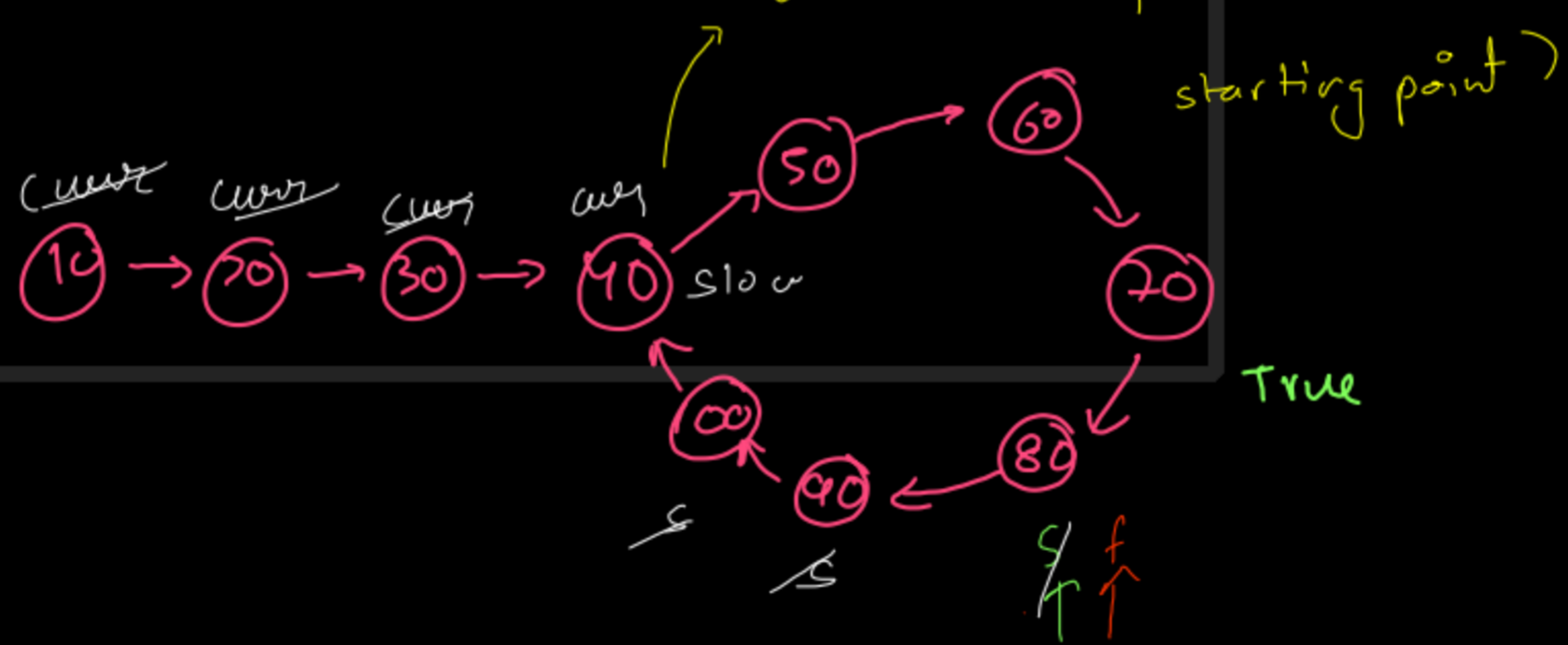
CSLL



Case 3

SLL

+ Loop

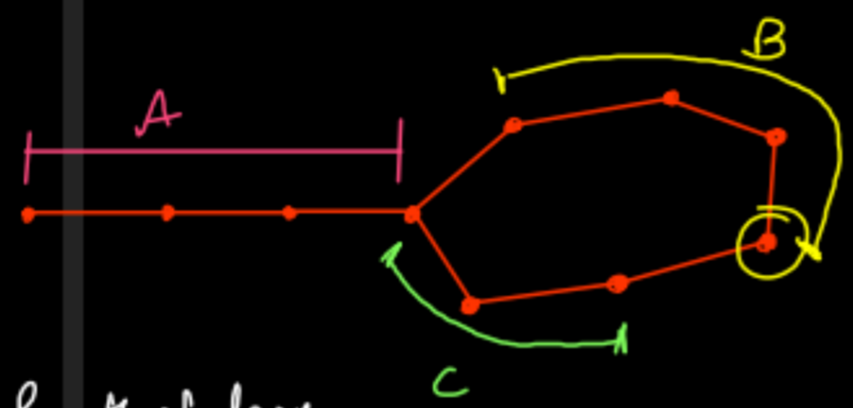


Code for Starting Pt of a Loop (LC 142)

```java
public ListNode detectCycle(ListNode head) {

    ListNode slow = head;
    ListNode fast = head;

    while(fast!=null && fast.next!=null) {
        slow = slow.next;
        fast = fast.next.next;

        if(slow == fast) break;
    }

    if(fast == null || fast.next == null) return null;

    ListNode curr1 = head;
    ListNode curr2 = slow;

    while(curr1 != curr2) {
        curr1 = curr1.next;
        curr2 = curr2.next;
    }

    return curr1;
}
```

O(N)

Mathematical Proof



length of loop $= B + C$

length of tail $= A$

slow = 1 node / itr

fast = 2 nodes / itr

Total time taken by slow = Total time taken by fast

$$\frac{d_{slow}}{S_s} = \frac{d_{fast}}{S_f}$$

$$d_{fast} = A + (B+C)j + B$$

↳ j loops travelled times

$$d_{slow} = A + (B+C)i + B$$

↳ i times loops travelled

{ $i = 0$ because slow does not travel any loop in curr example }

$$\frac{d_{slow}}{s_s} = \frac{d_{fast}}{s_f}$$

$$\frac{A+(B+C)i+B}{s_s} = \frac{A+(B+C)j+B}{s_f}$$

relative speed of fast w.r.t slow (r)

$$\frac{s_f}{s_s}\{A+(B+C)i+B\} = A+(B+C)j+B$$

$$rA + r(B+C)i + rB = A+(B+C)j+B$$

$$rA + rB - A - B = (B+C)\{j - ri\}$$

$$(r-1)(A+B) = (B+C)(j-ri)$$

$$A+B = (B+C)\left\{\frac{j-ri}{r-1}\right\}$$

$$\frac{j-ri}{r-1} = k$$

$$\boxed{A = (B+C)k - B}$$

tail

some cycles

A = some cycles − tail

shorting of B

Hence Proved

$$\boxed{A = (B+C)k - B}$$

tail

some cycles

This can also be understood as

$$A = (B+C)k' + C$$

uske baad C chalega

$\Downarrow$

some no of cycles

Simple Proof (Explanation for Interviews)

$d_{slow} = A + cycle(i) + B$ $\quad \{ S_{fast} = 2 * S_{slow} \}$

$d_{fast} = A + cycle(j) + B$

$d_{fast} = * \, 2 \, dist_{slow}$

$A + cycle(j) + B = 2(A + cycle(i) + B)$

$A + cj + B = 2A + c2i + 2B$ $\longrightarrow$ cycle ko again c liken de

$$\boxed{A = c(j - 2i) - B}$$

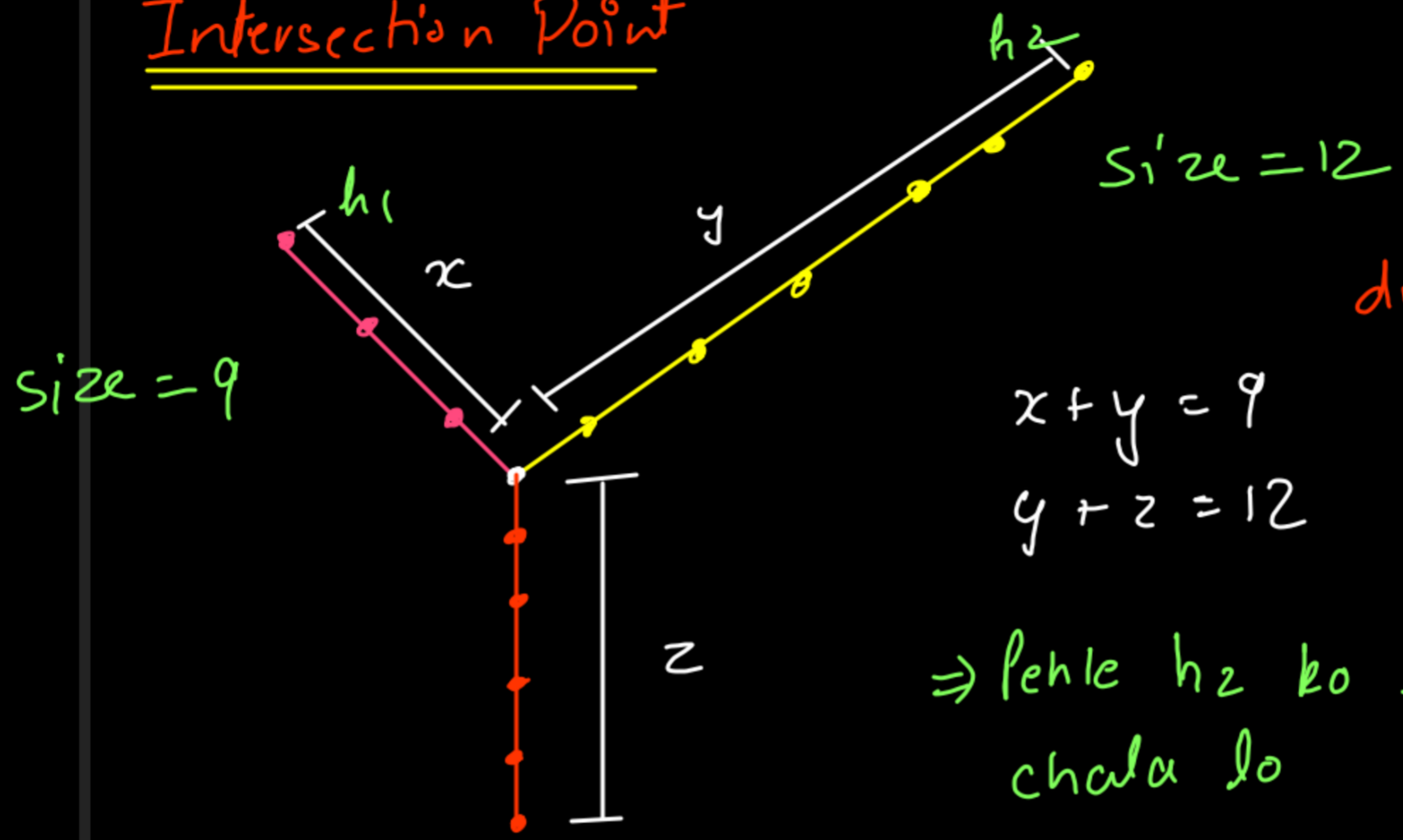
Remove Loop $\Rightarrow$ HW

Length of the Loop (GfG)

```
static int countNodesinLoop(Node head)
{

    Node slow = head;
    Node fast = head;

    while(fast!=null && fast.next!=null) {
        slow = slow.next;
        fast = fast.next.next;

        if(slow == fast) break;
    }

    if(fast == null || fast.next == null) return 0;

    Node curr1 = head;
    Node curr2 = slow;

    while(curr1 != curr2) {
        curr1 = curr1.next;
        curr2 = curr2.next;
    }

    Node p = curr1;
    int dist = 1;
    p = p.next;
    while(p != curr1) {
        p = p.next;
        dist +=1;
    }

    return dist;
}
```

find the starting point of the loop & then traverse the loop.

Intersection Point



diff = 12 - 9
= 3

$x + y = 9$

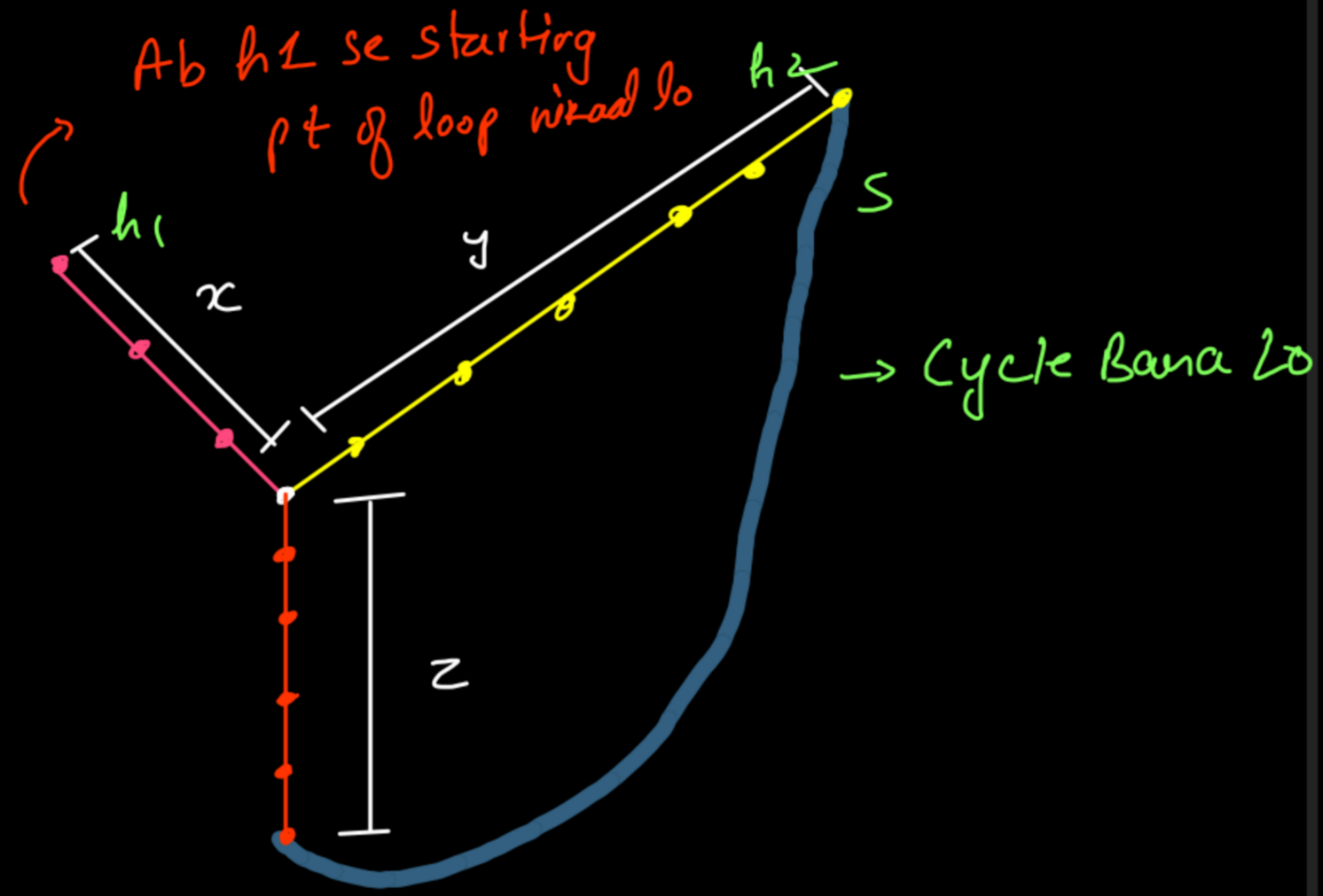
$y + z = 12$

⇒ Pehle h_2 ko 3 baar chala lo

⇒ Jab tak dono barabar nahi hote dono ko chalao

Intersection Point

```java
public ListNode getIntersectionNode(ListNode headA, ListNode headB) {
    int sizeA = getSize(headA);
    int sizeB = getSize(headB);

    if(sizeA > sizeB) {
        for(int i=0;i<sizeA-sizeB;i++)
            headA = headA.next;
    } else {
        for(int i=0;i<sizeB-sizeA;i++)
            headB = headB.next;
    }

    while(headA != headB) {
        headA = headA.next;
        headB = headB.next;
    }

    return headA;
}
```


Ab h1 se starting
pt of loop nikaal lo
h1
h2
x
y
z
S
→ Cycle Bana Lo

Using floyd's Cycle

```java
public ListNode getIntersectionNode(ListNode headA, ListNode headB) {
    ListNode tailB = headB;
     while(tailB.next != null) {
         tailB = tailB.next;
     }

     tailB.next = headB;
     ListNode ans = detectCycle(headA);
     tailB.next = null;
     return ans;
 }
```