Linked List (Level 1 + Level 2)

Lecture ① {Monday}

→ LL Basics

→ Display, Get At

→ Add
- Last
- First

→ Remove
- Last
- First

Lecture ② {Tuesday}

→ Add At

→ Remove At

LC 707 Design LL

→ Reverse Linked List LC 206

→ Data Iterative $O(N^2)$

→ Pointer Iterative $O(N)$

→ Data Recursive $O(N)$

- Local
- Return
- Static

Lecture 3 {Wednesday}

- → Display Reverse
- → Reverse LL
  Pointer Recursion
- → k Reverse LC HARD 25
- → Middle Node LC 876
- → Kth node from end GFG
- → Palindrome LL LC 234

Lecture 4 {Thursday}

- → Merge LL
  - → merge 2 sorted LC 21
  - → merge K sorted LC HARD 23
  - → merge sort LC 148
- → Big Integers
  - → Addition of LL
  - → Subtraction of LL

Monday Lecture 7 {8:30 PM to 12 AM}

→ Big Integers → subtractn
→ multiplication

→ Remove Duplicates (1&11) LC 83 & 82

→ Fold & unfold LL LC 143 & Pepcoding

→ Remaining Problems.

ArrayList is an array of dynamic array → contiguous

Arrays : Contiguous memory Allocation

int[] arr = new int[100];

O(1) get

Random Access

Memory is available

⇓

fragmentation

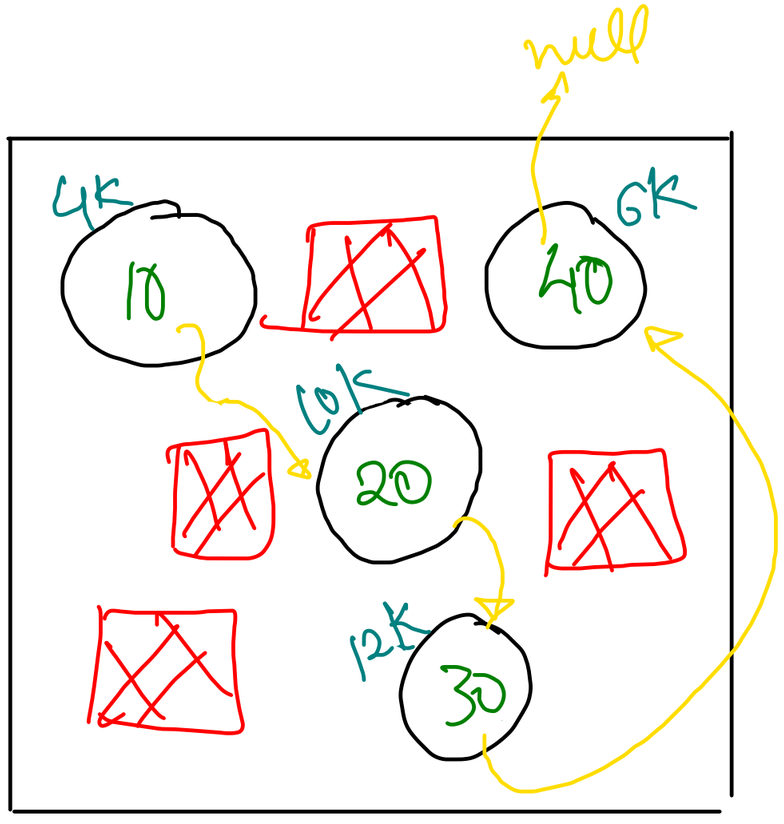
16 bytes

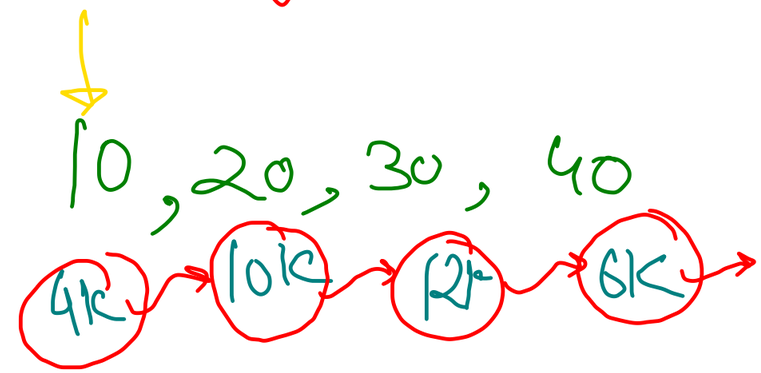
4k {10, 20, 30, 40}

Base index, index, size

Address of ith ele = Base Add + (index) * size

Singly linked list :→ Non contiguous memory allocation





class → Data member, Functions

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

extra memory

```
public static
linkedlist {
    Node head;
    Node tail;
    int size;
}
```

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

```java
public static class LinkedList{
    Node head;

    public void display(){

    }

    public void addFirst(int val){

    }

    public void addLast(int val){

    }

    public int get(int idx){

    }
}
```

Node fail; int size

Main( ) {

→ LinkedList list = new LinkedList();

→ list.addLast(10);

→ list.addLast(20);

→ list.addLast(30);

→ list.addLast(40);

Stack

list = 2k

heap

2k

Head = 4k
Tail = 6k
size = 4

linkedlist's

10	20	30	40
10k	12k	6k	n
4k	10k	12k	6k

{ }

↓

{10}

↓

{10 → 20}

↓

{10 → 20 → 30}

↓

{10 → 20 → 30 → 40}

Array
16 bytes
vs
LL
4 nodes → (4 bytes + 8 bytes) * 4
LL obj → (8 + 8 + 4) = 20 bytes

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

public static class LinkedList {
  Node head;
  Node tail;
  int size;

  void addLast(int val) {
      // 1. Create a new Node
      Node temp = new Node();
      temp.data = val;

      if(size == 0){
          // new Node is the first as well as the last node
          head = temp;
          tail = temp;
      } else {
          tail.next = temp;
          tail = temp;
      }

      size++;
  }
}
```

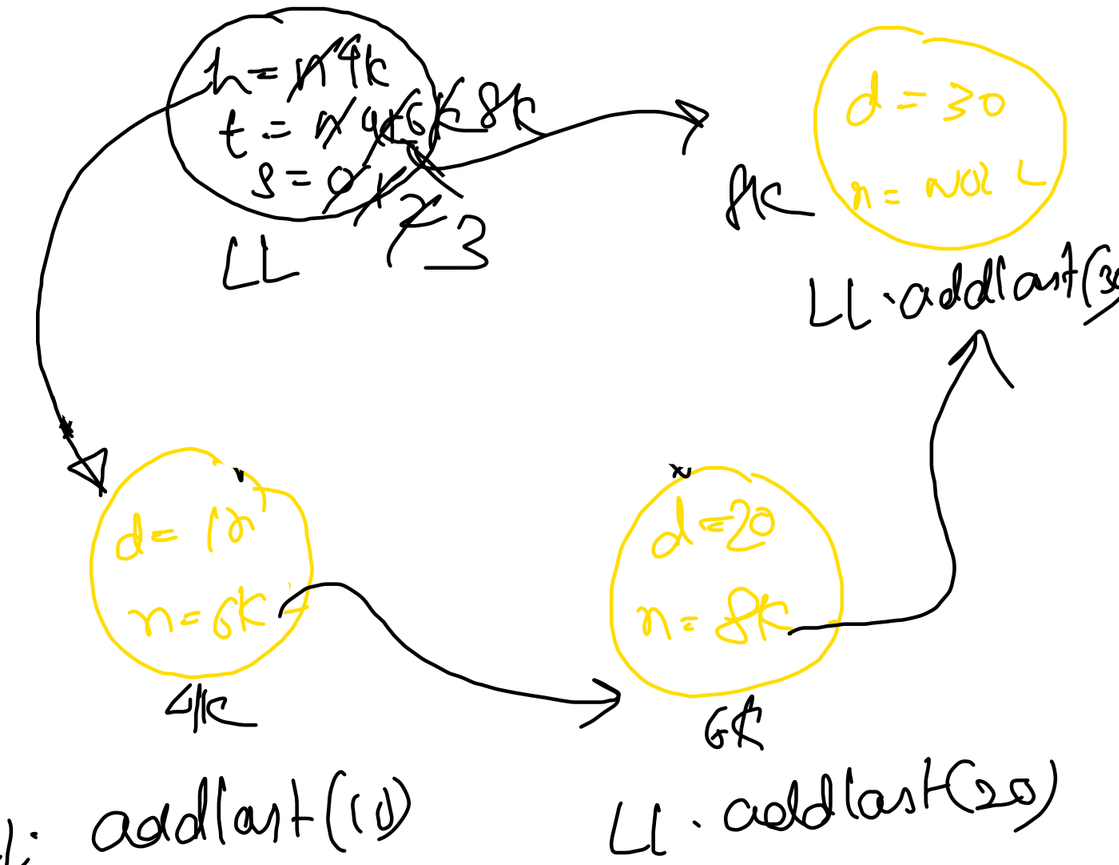
tail

O(1)

If tail was not given

⇒ addLast would have costed O(n)

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



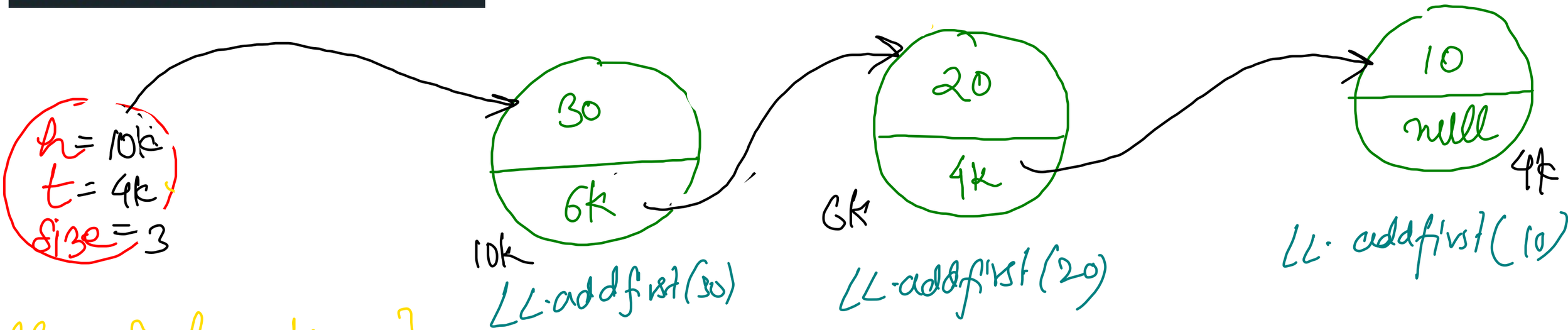
Disadvantages of linked list over Array

1. → Extra space for storing 1 Node
2. → Random Access not available.

Advantages of linked list over Array

1. → Non-contiguous memory allocation
2. → NO problem of fragmentation.

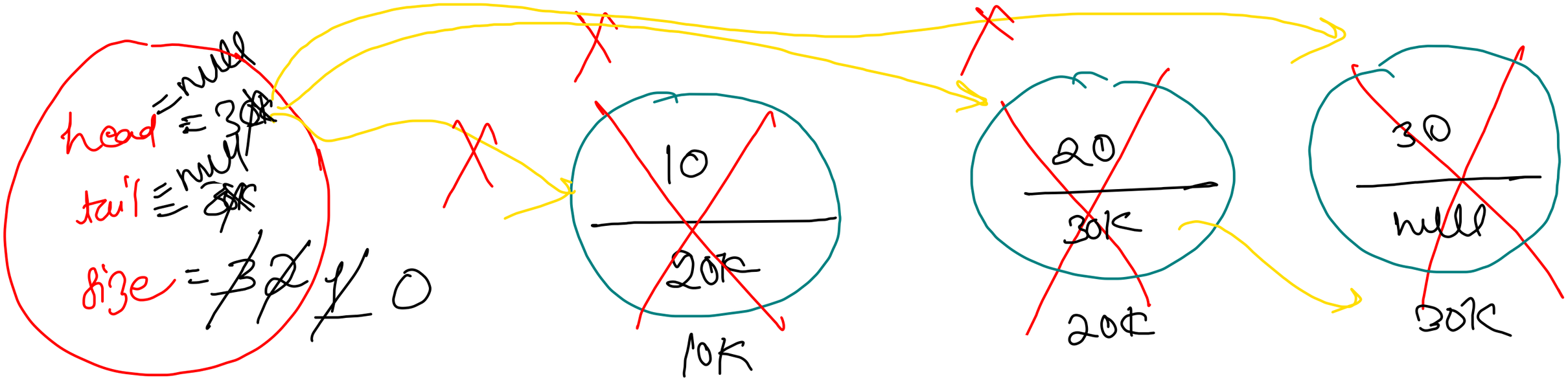
```
LinkedList list = new LinkedList();
```

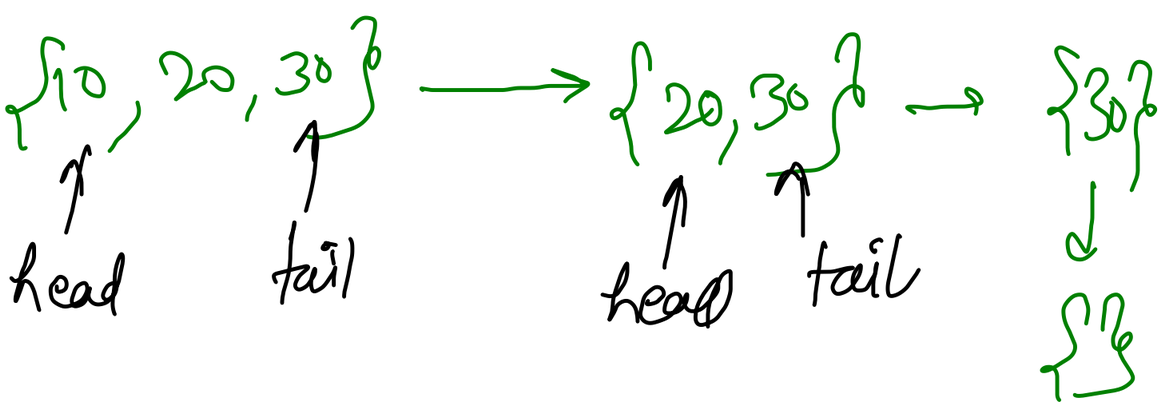


{} → {10} → {20, 10} → {30, 20, 10}

```
public void addFirst(int val) {
    // Creation of new Node
    Node temp = new Node();
    temp.data = val;

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

    size++;
}
```

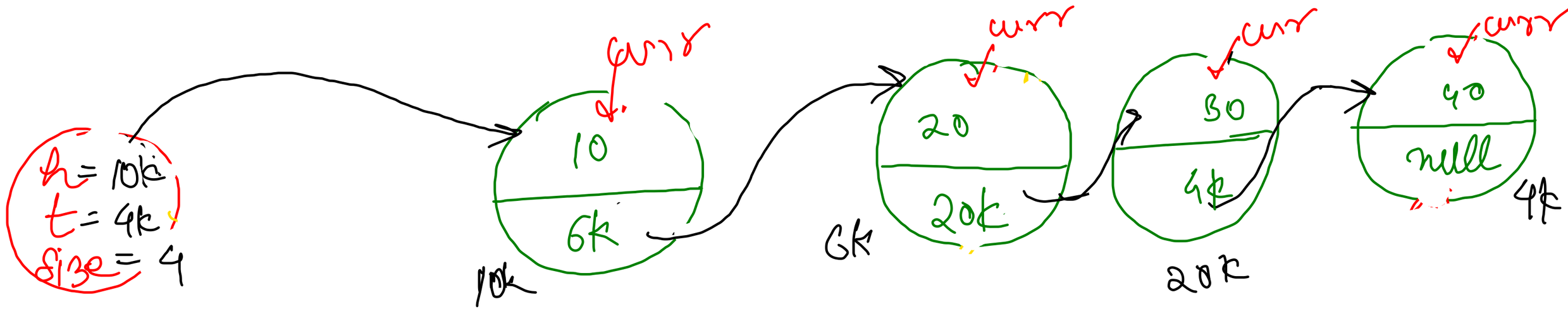
O(1)






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

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

O(1)



"Traversing/Displaying" a LL

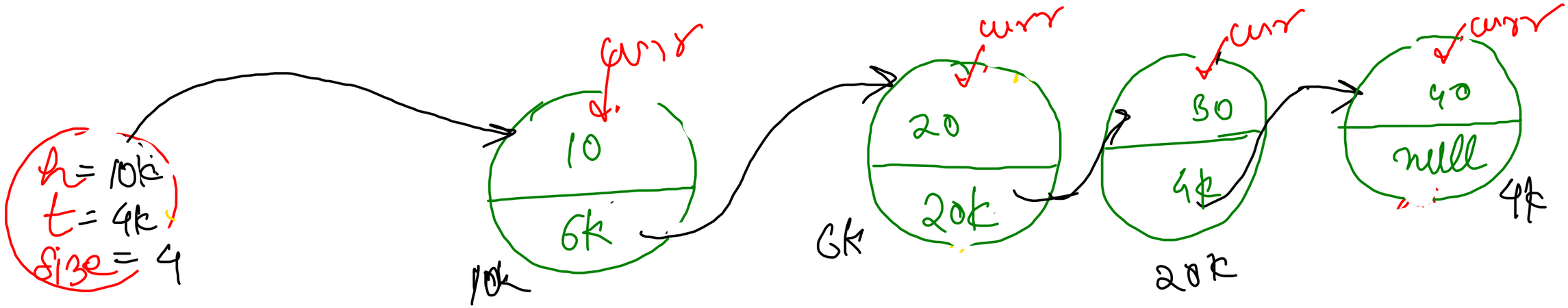
10, 20, 30, 40

1st 2nd 3rd 4th

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

OR

```
public void display(){
    if(size == 0){
        return;
    }

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



3.1. getFirst - Should return the data of first element. If empty should return -1 and print "List is empty".

3.2. getLast - Should return the data of last element. If empty should return -1 and print "List is empty".

3.3. getAt - Should return the data of element available at the index passed. If empty should return -1 and print "List is empty". If invalid index is passed, should return -1 and print "Invalid arguments".

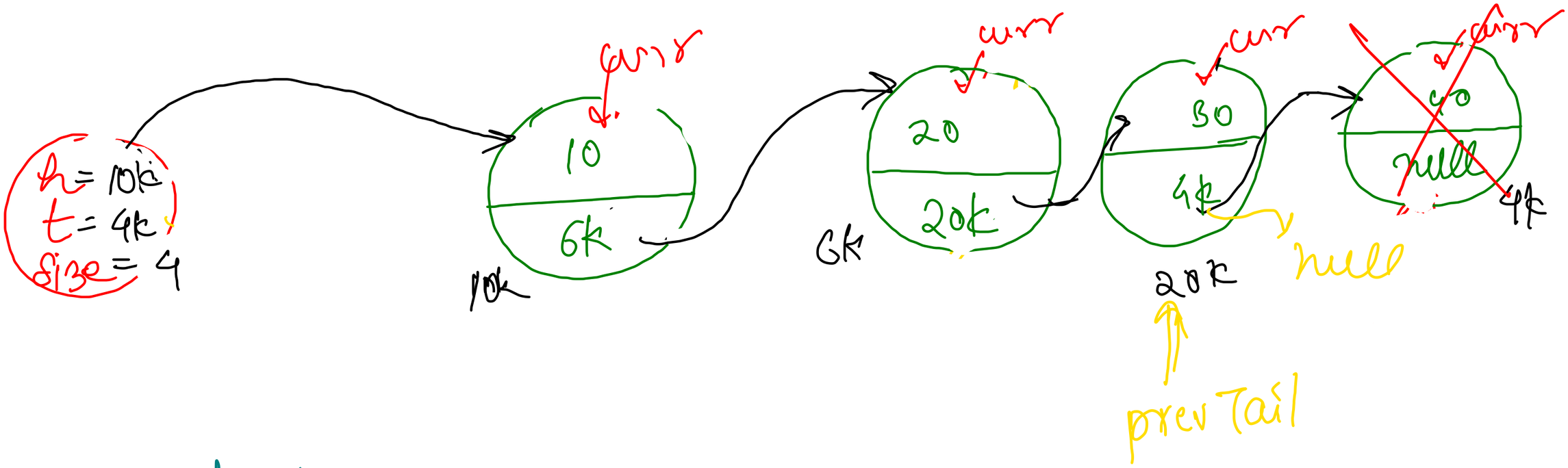
1. getFirst() → getAt(0) → 10 (loop → 0 times)
2. getLast() → getAt(size-1) → 40 (loop → (size-1) times)
3. getAt(1) → 20 (loop → 1 times); getAt(2) → 30 (loop → 2 times)

corner cases

1. getAt(-1), getAt(5) → "Invalid Arg" return -1
2. Empty list

```java
public int getFirst(){
    if(size == 0){
        System.out.println("List is empty");
        return -1;
    }

    return head.data;
}

public int getLast(){
    if(size == 0){
        System.out.println("List is empty");
        return -1;
    }

    return tail.data;
}

public int getAt(int idx){
    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;
}
```

$O(N)$



Remove last

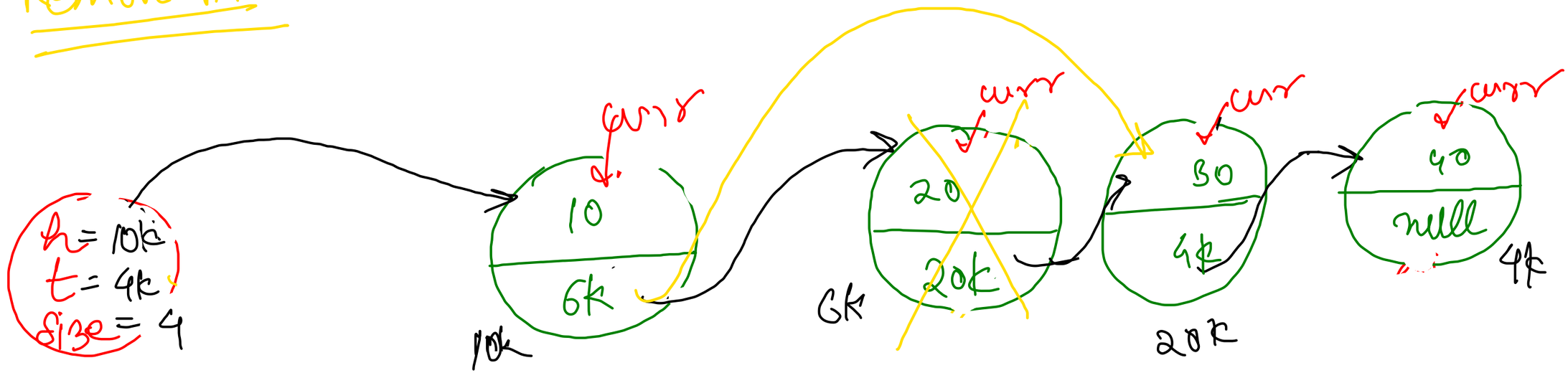
if size > 1

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

```java
public void removeLast(){
    if(size == 0){
        System.out.println("List is empty");
        return;
    }

    if(size == 1){
        head = tail = null;
    } else {
        Node prevTail = head;
        for(int i=0; i<size-2; i++){
            prevTail = prevTail.next;
        }

        prevTail.next = null;
        tail = prevTail;
    }

    size--;
}
```

$\rightarrow O(n)$

Remove At



① remove At(0) → removeFirst()

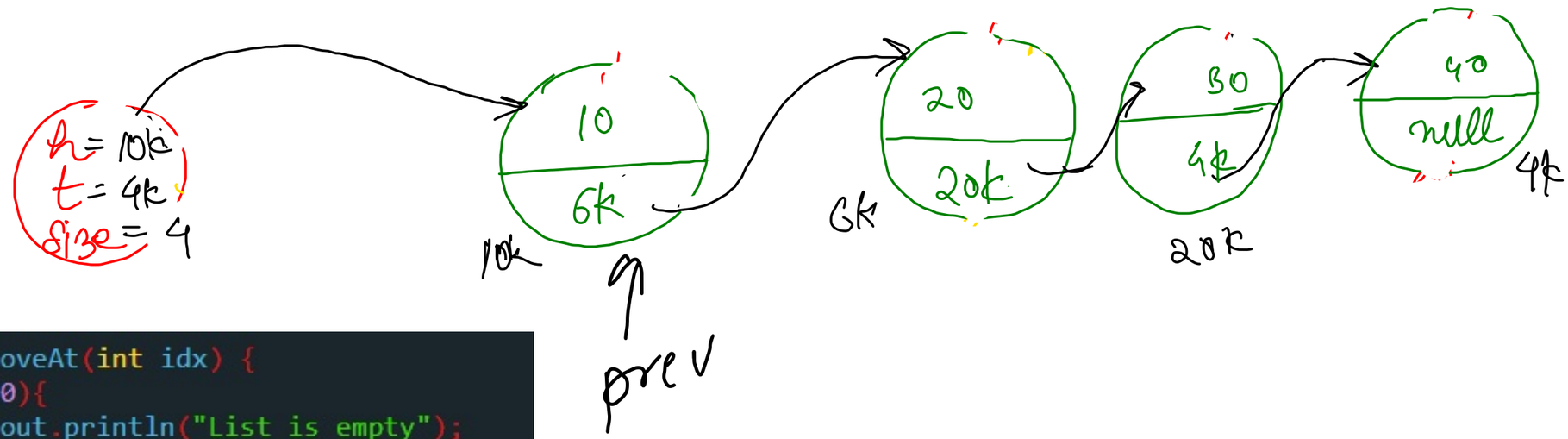
② removeAt(size-1) → removeLast()

③ removeAt(idx) → ① Get idx-1 th node O(N)
② prev.next = prev.next.next
③ size--;

{ 0 < idx < size-1 }

idx < -1, ≥ size } invalid arg

size == 0 } List is empty



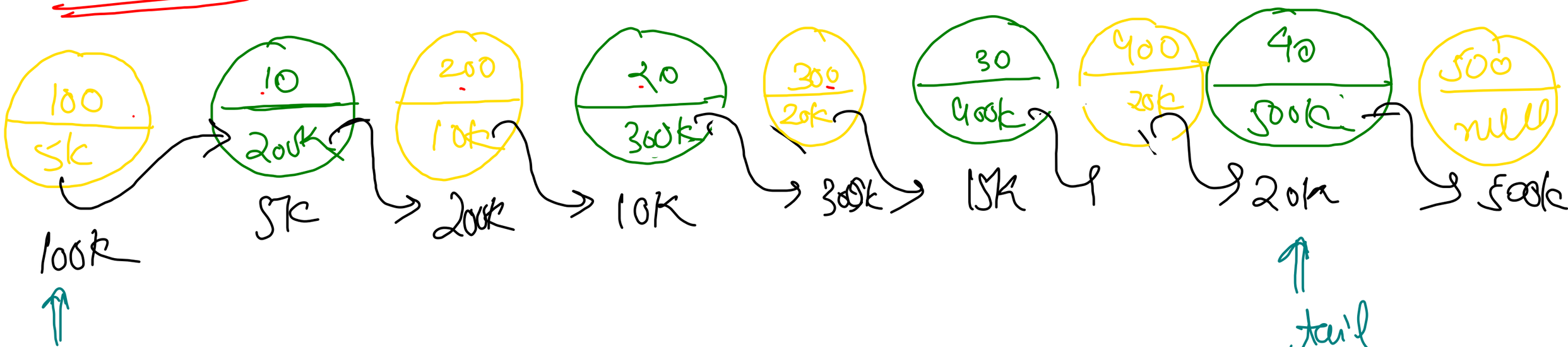

```java
public void removeAt(int idx) {
    if(size == 0){
        System.out.println("List is empty");
        return;
    }

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

    if(idx == 0) removeFirst();
    else if(idx == size - 1) removeLast();
    else {
        Node prev = head;
        for(int i=0; i<idx-1; i++){
            prev = prev.next;
        }

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

O(N) in worst case

LL.removeAt(2)

Worst O(N)

Add At



AddAt(0, 100) ⇒ addFirst(100);

AddAt(2, 200)

AddAt(4, 300)

size-1

AddAt(6, 400) ⇒ Add at second last

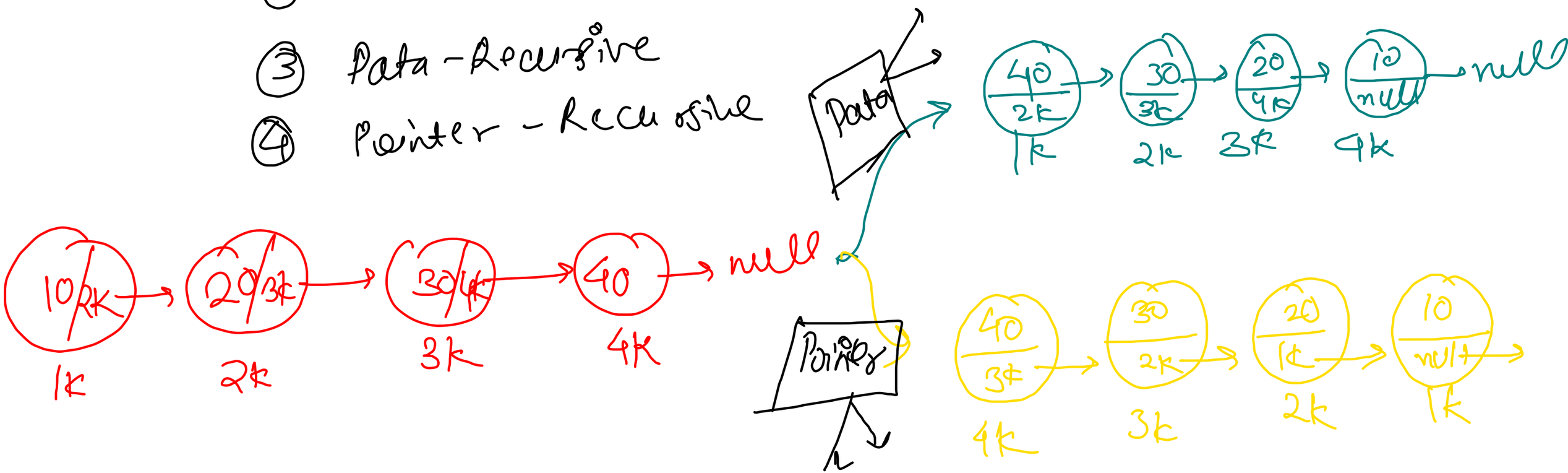
AddAt(8, 500) ⇒ AddLast

size

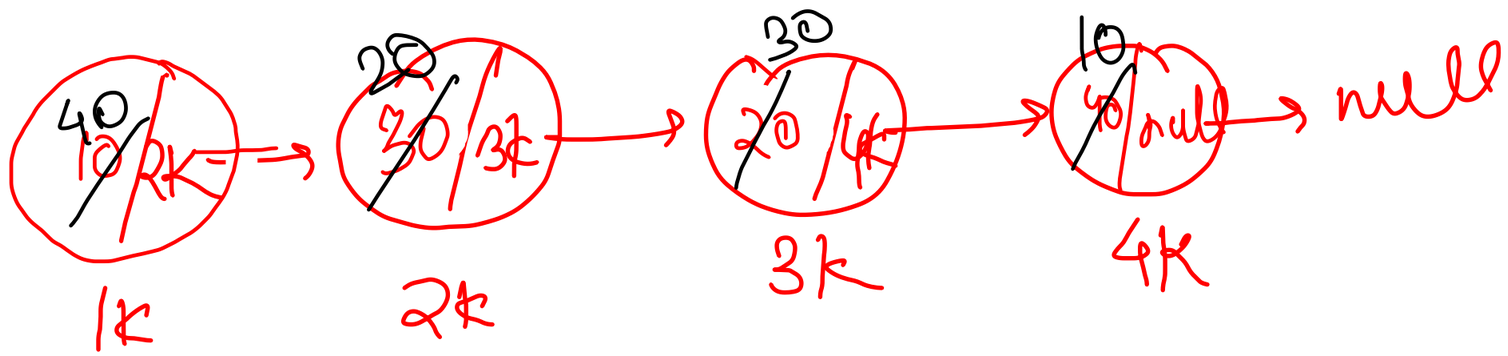
```java
public void addAt(int idx, int val){
    if(idx < 0 || idx > size){
        System.out.println("Invalid arguments");
        return;
    }

    if(idx == 0) addFirst(val);
    else if(idx == size) addLast(val);
    else {
        Node temp = new Node();
        temp.data = val;

        Node prev = head;
        for(int i=0; i<idx-1; i++){
            prev = prev.next;
        }

        temp.next = prev.next;
        prev.next = temp;
        size++;
    }
}
```

Reverse a linked list

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



Data Iterative

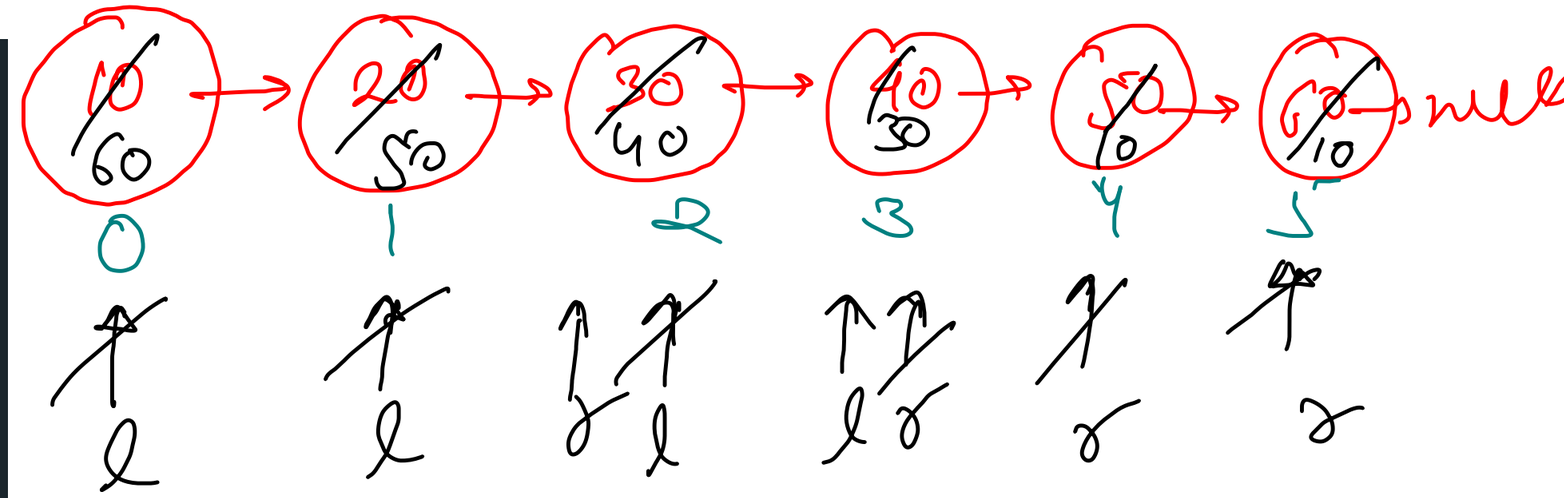


right left

```
while(left < right){
  ① leftNode = getAt(0)
     rightNode = getAt(n-1)
     ⇒ O(N)
     left++ right--

  ② left N = getAt(1)
     right N = getAt(n-2)
     ⇒ O(N)
}
```

Time Comp ⇒ $\frac{N}{2} * O(N) = O(N^2)$

```java
public Node getNodeAt(int idx){
    Node curr = head;
    for(int i=0; i<idx; i++){
        curr = curr.next;
    }
    return curr;
}

public void swap(Node left, Node right){
    int leftData = left.data;
    left.data = right.data;
    right.data = leftData;
}

public void reverseDI() {
    int left = 0, right = size - 1;
    while(left < right){
        Node leftNode = getNodeAt(left);
        Node rightNode = getNodeAt(right);

        swap(leftNode, rightNode);
        left++; right--;
    }
}
```



$O(N) \rightarrow (0,5)$

$O(N) \rightarrow (1,4)$

$O(N) \rightarrow (2,3)$

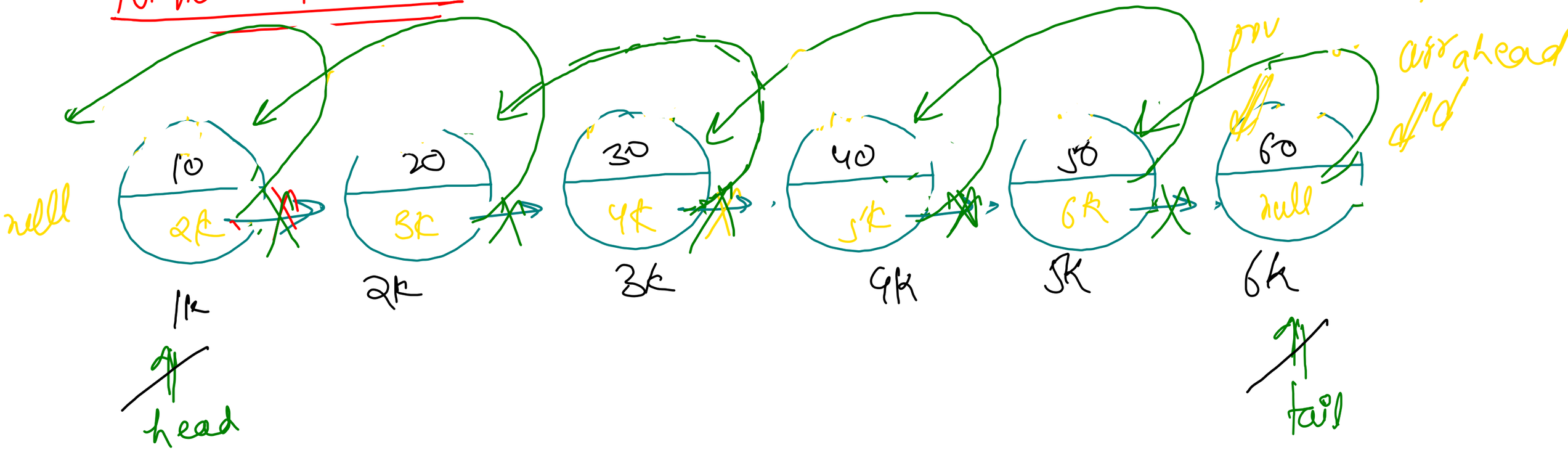
} 3 swaps

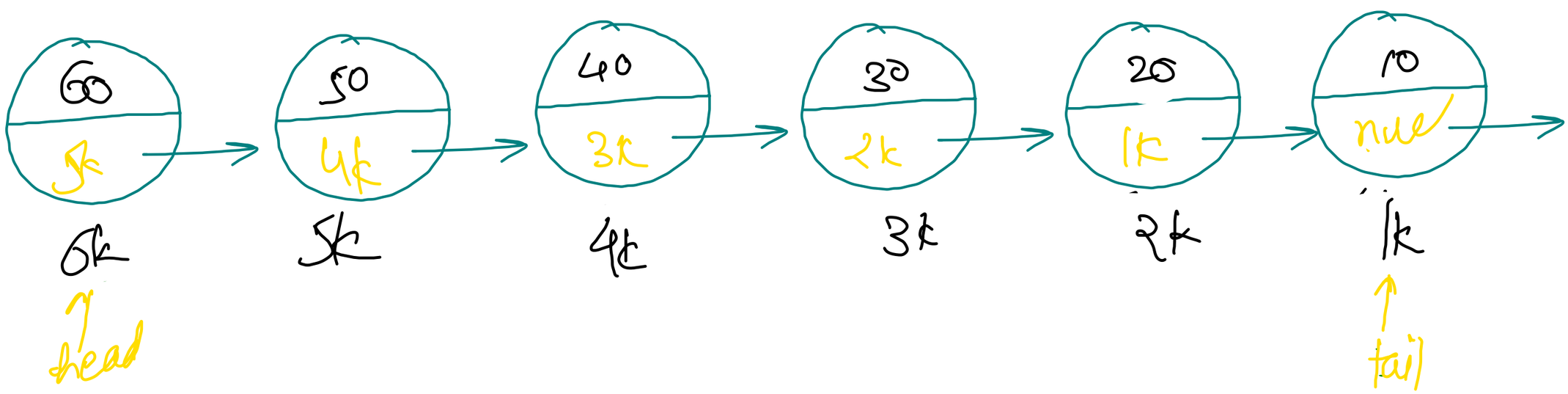
$\frac{N}{2} * O(2N)$

$\rightarrow O(N^2)$

Pointer - Iterative

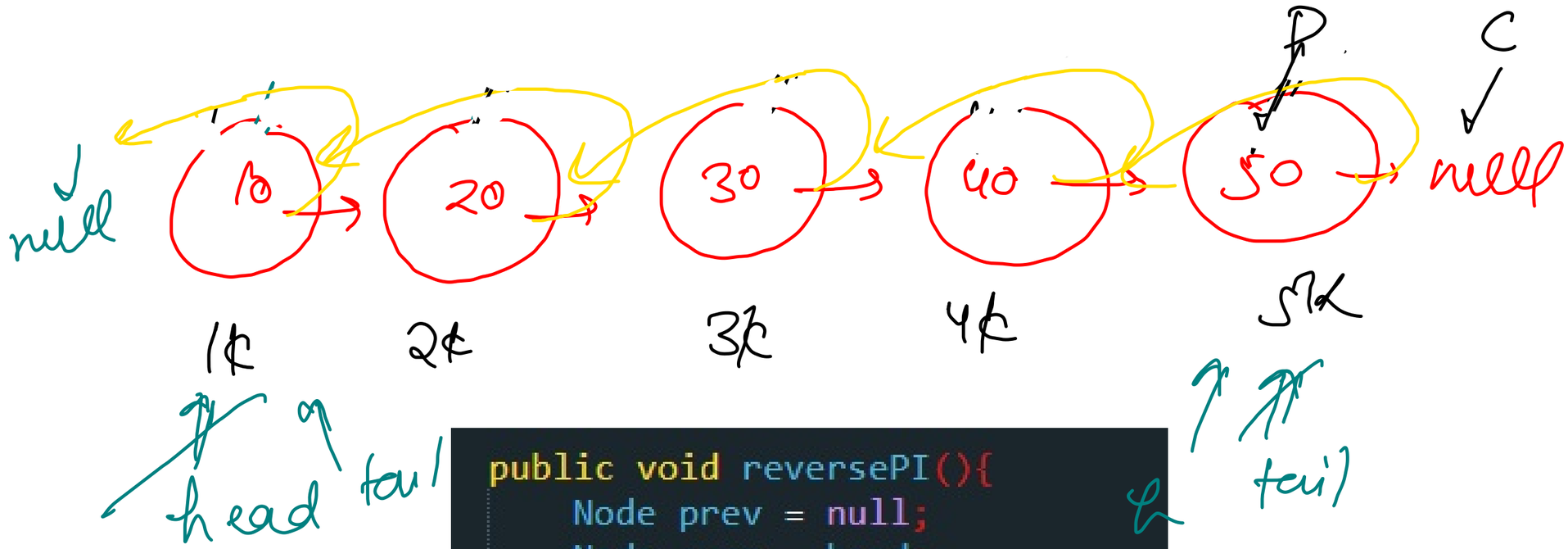
curr-next = prev





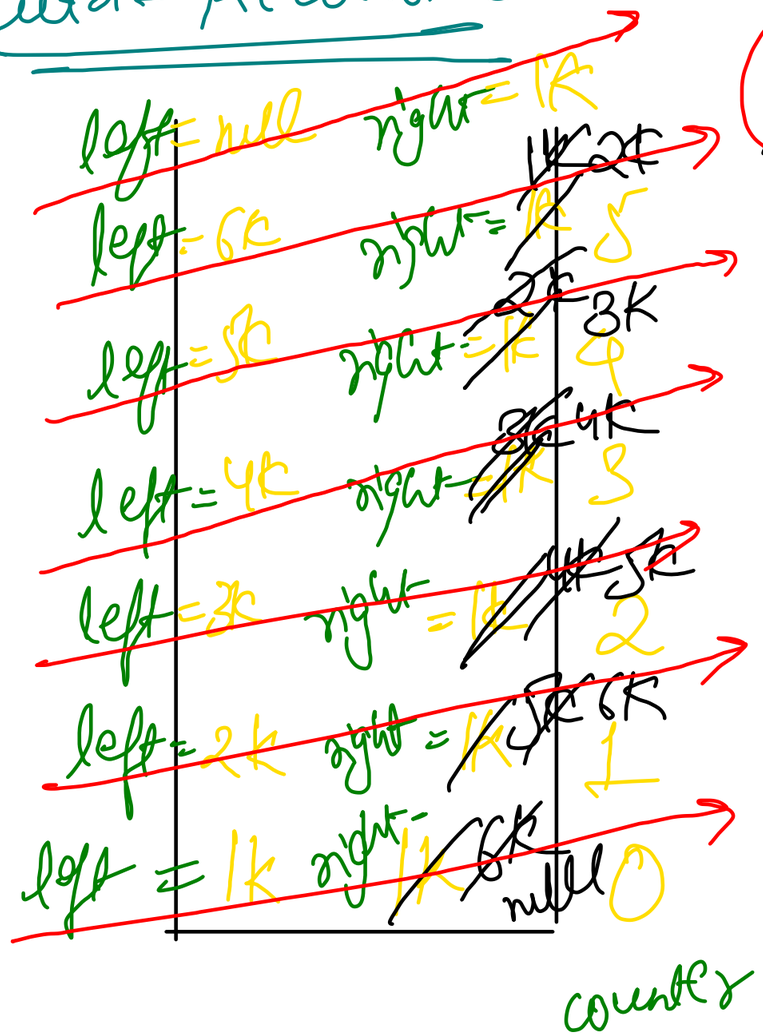
```
Node prev = null, curr = head;
while (curr != null) {
    Node ahead = curr.next;
    curr.next = prev;
    prev = curr; curr = ahead;
}
swap(head, tail)
```

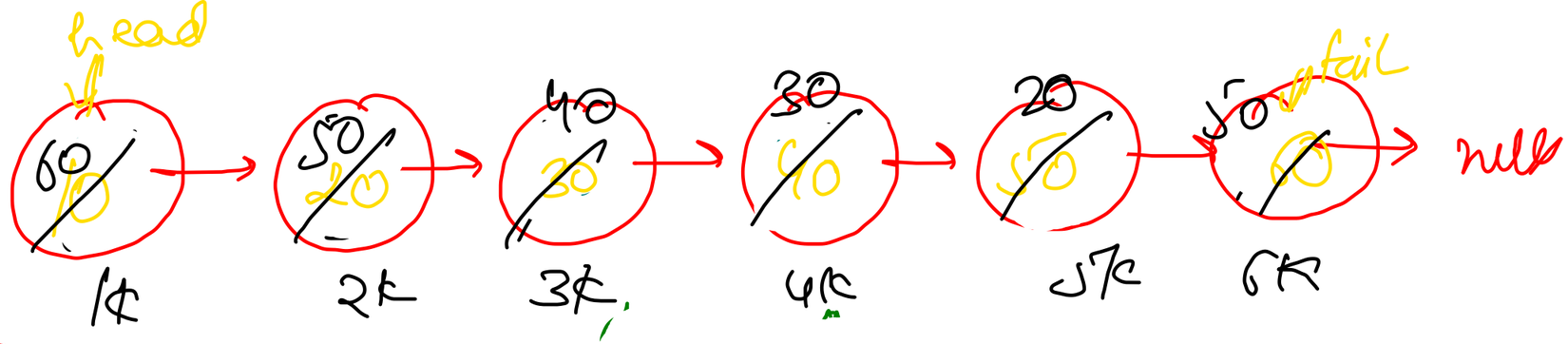
1. Even
2. Odd
3. 1 Node
4. 0 Node




```java
public void reversePI(){
    Node prev = null;
    Node curr = head;

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

    Node temp = head;
    head = tail;
    tail = temp;
}
```

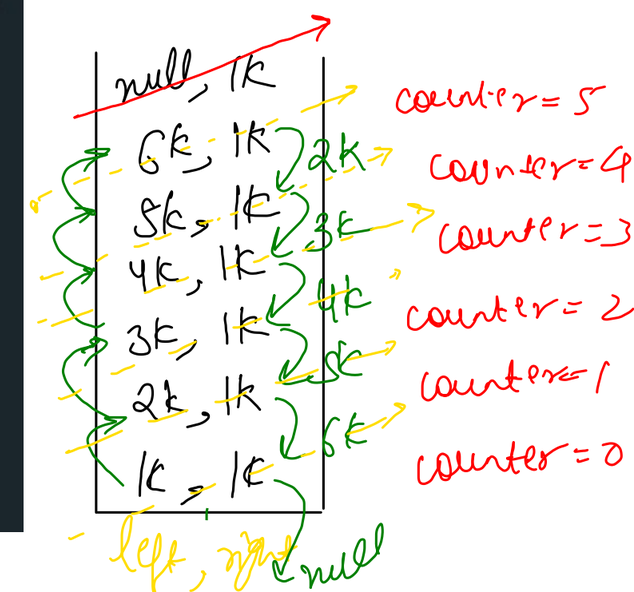
Data - Recursive



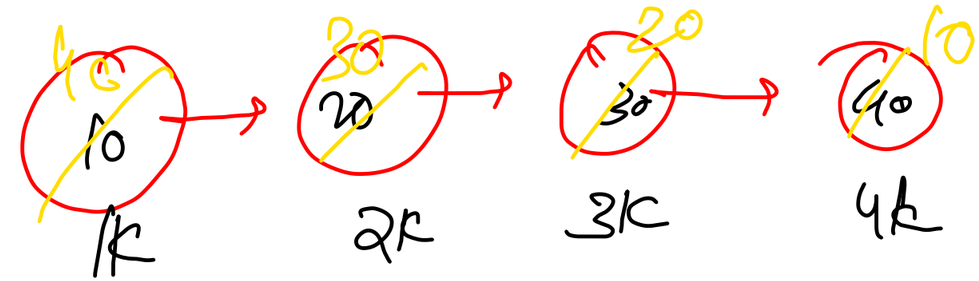


$$(1)^n + (k+k) * n = \boxed{O(n)}$$

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

    right = reverseDR(left.next, right, counter + 1);

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

    right = right.next;
    return right;
}
```



```java
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);
}
```

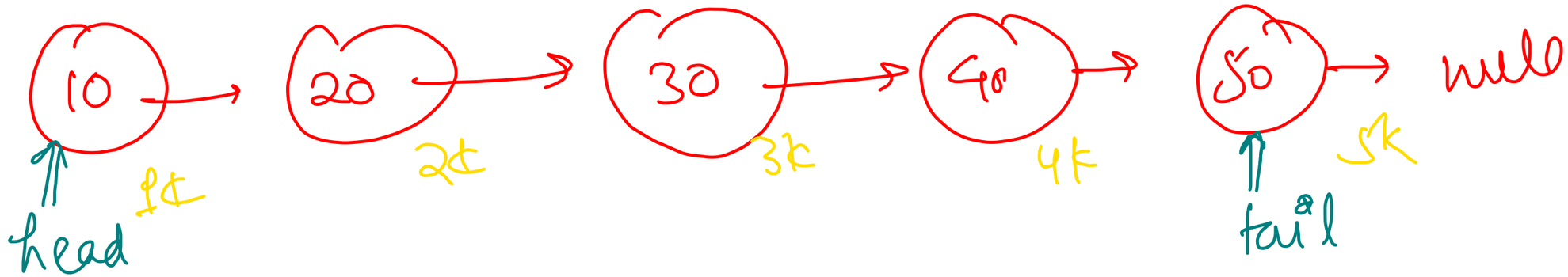


~~left~~	~~null~~
~~left~~	~~4K, 3~~
~~left~~	~~3K, 2~~
~~left~~	~~2K, 1~~
~~left~~	~~1K, 0~~

heap

right = ~~1K~~ ~~2K~~ ~~3K~~ ~~4K~~ null

Display Reverse {Recursion}

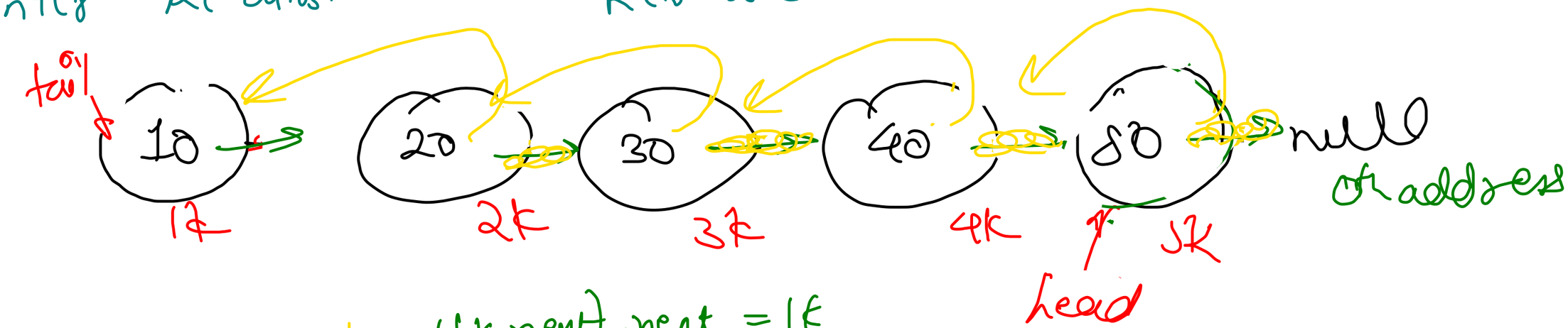


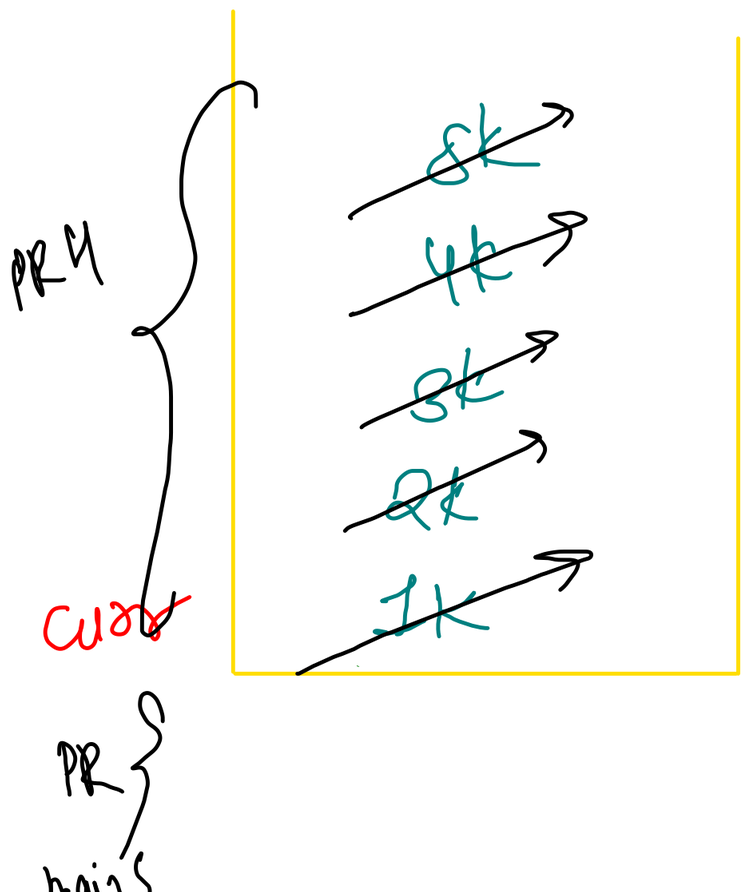
50 , 40 , 30 , 20 , 10

```java
private void displayReverseHelper(Node node){
    if(node == null) return;

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

$O(N)$

Pointer Recursive → Reverse ll





(1k.next).next = 1k

⇓

2k.next = 11

node.next.next = node;

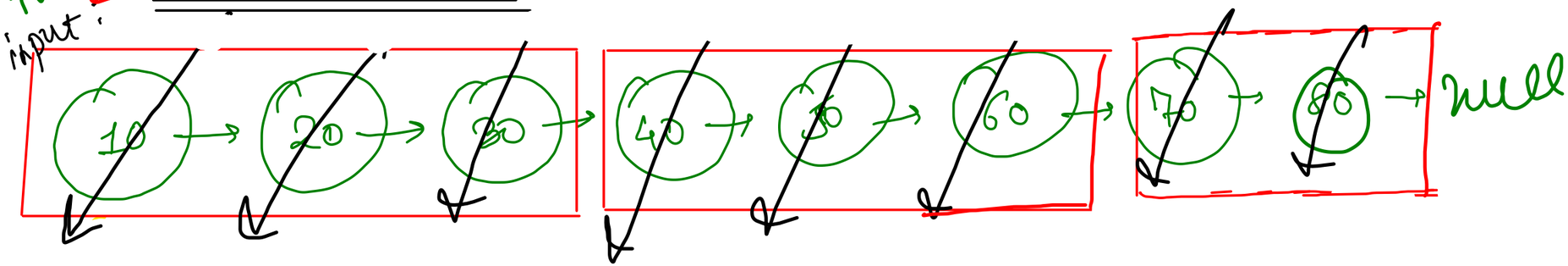
```
private void reversePRHelper(Node node){
    if(node == null || node.next == null){
        return;
    }

    reversePRHelper(node.next);

    // Update link of next node
    node.next.next = node;
}
```

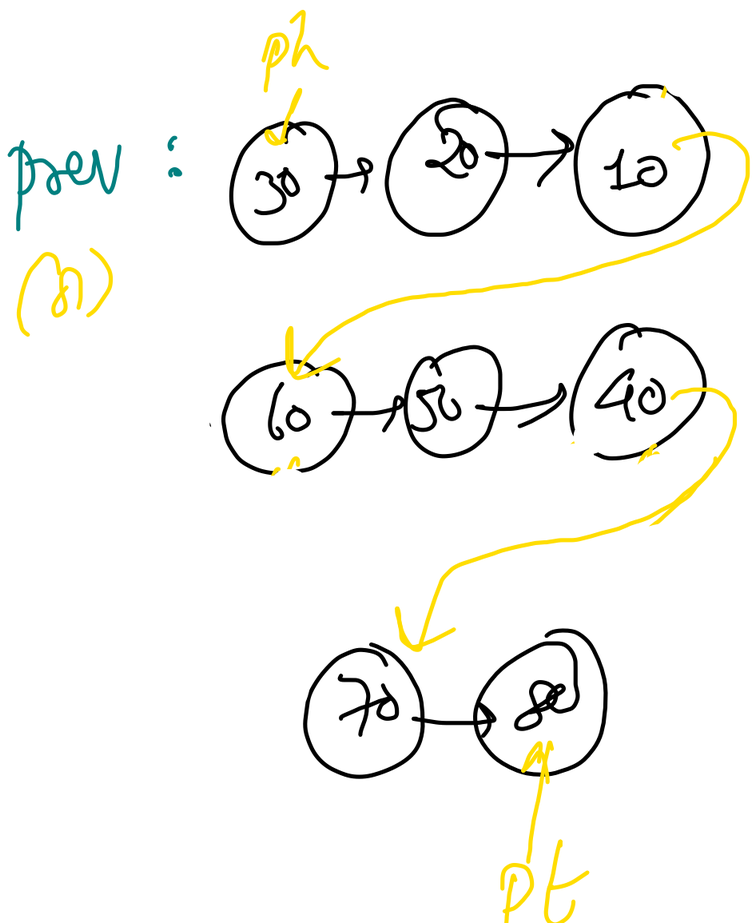
```
public void reversePR(){
    Node curr = head;
    reversePRHelper(curr);

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

    // make tail's node next as null
    tail.next = null;
}
```

Reverse k

size = 8

k = 3





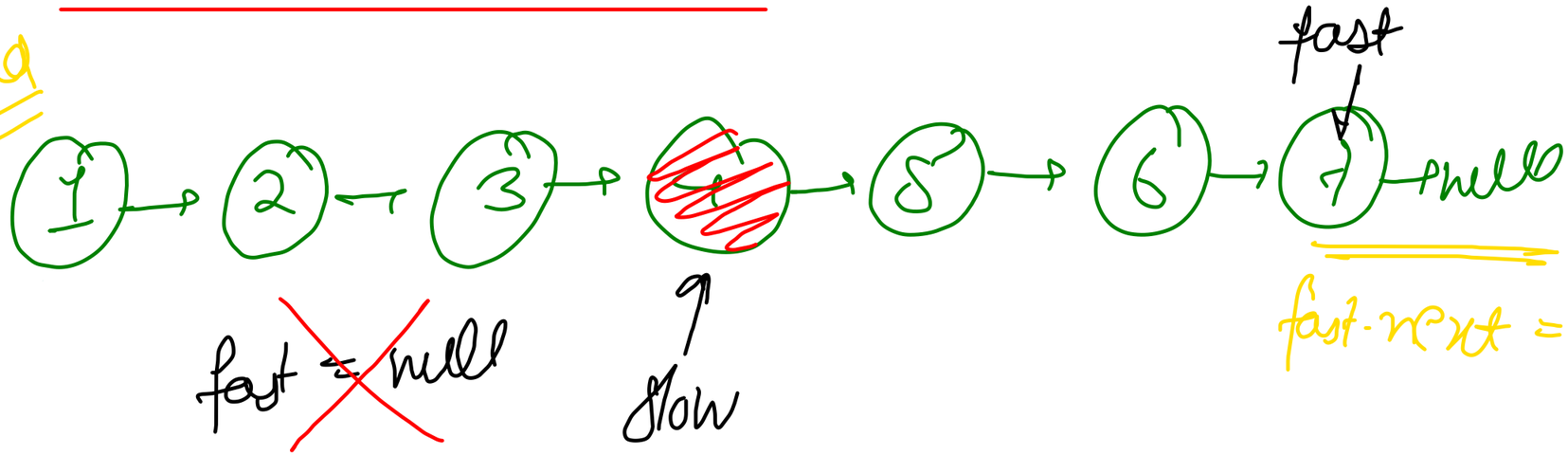

```java
LinkedList prev = new LinkedList();

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

    if(size < k){
        // if group is partially filled
        while(size > 0){
            int val = head.data;
            this.removeFirst();
            curr.addLast(val);
        }
    }

    else {
        // extracting a group of size k
        for(int i=0; i<k; i++){
            int val = head.data;
            this.removeFirst();
            curr.addFirst(val);
        }
    }
```

```java
    if(prev.head == null){
        // when we have extracted our first group (30, 20, 10)
        prev = curr;
    } else {
        // adding one group of size k in the prev linked list
        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;
```

876 LC

Middle Linked list { Hare & Tortoise } { Two pointer }

odd

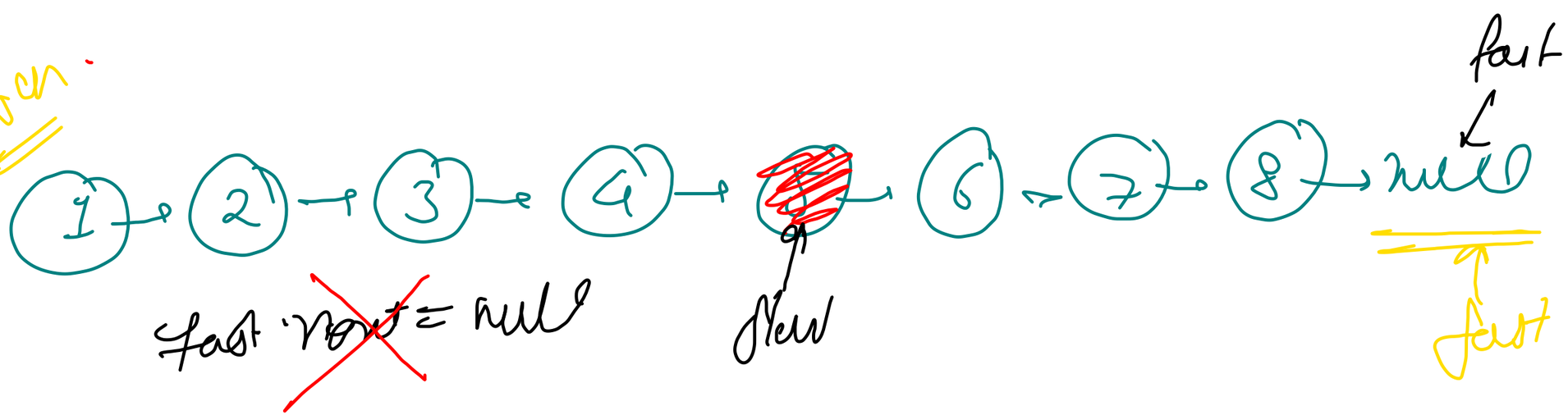


fast.next = null

① Two traversal

get $\left\{ \left(\frac{size}{2} \right) + 1 \right\}$

even



fast == null

O(N)

```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;
}
```

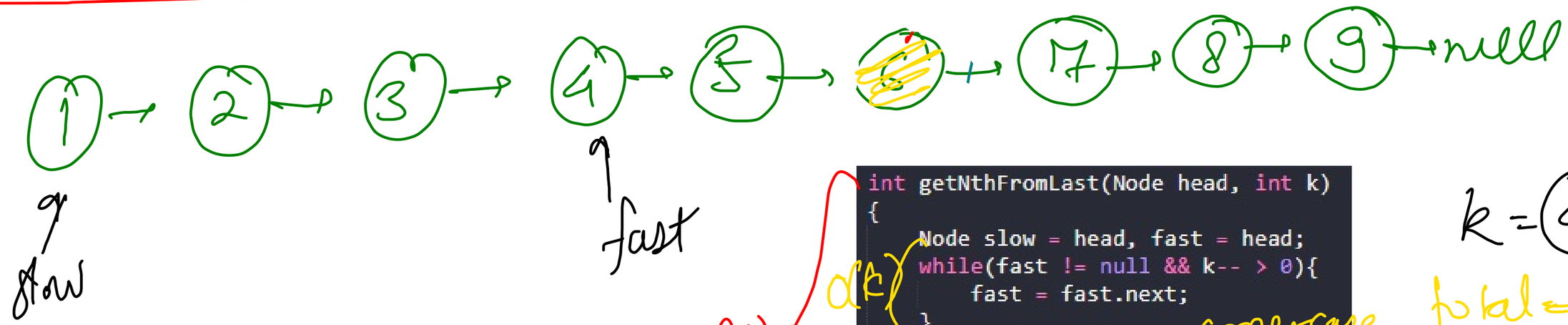
O(N)

```java
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;
}
```

O(N)

```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;
}
```

Kth Node from End




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

$O(k)$

$O(N)$

cornercase $k > N$

$k = 4$

total $= 9 = N$

1st Appr : 2 Traversal

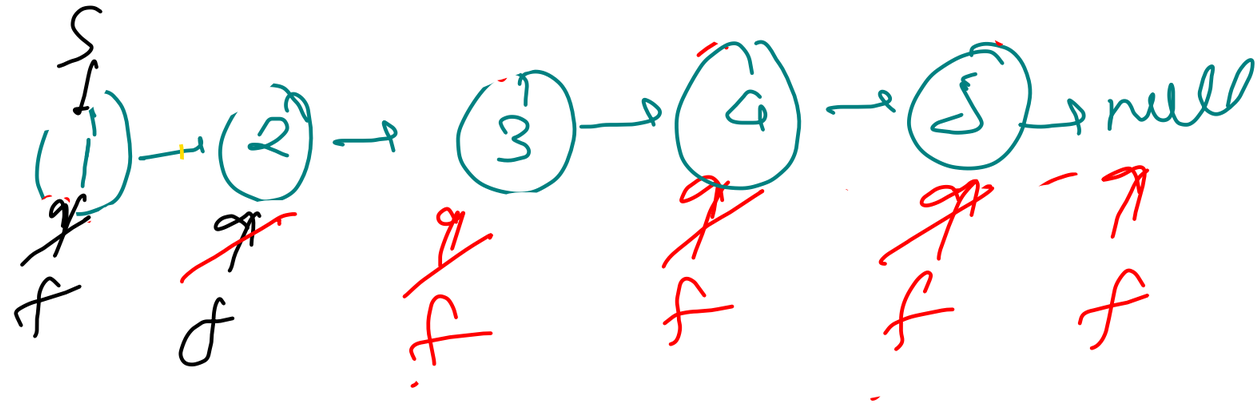
→ count No of nodes in LL ⇒ N

→ get(N − k)
9 − 4

2nd Appr : Single traversal
{ Two pointer }

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

Maintain diff



$k = \cancel{5}\ \cancel{4}\ \cancel{3}\ \cancel{2}\ \cancel{1}\ 0 \Rightarrow 1$

Both fast became null & k = 0 together

$k = \cancel{1}\ 0 \Rightarrow 5$ → k became 0

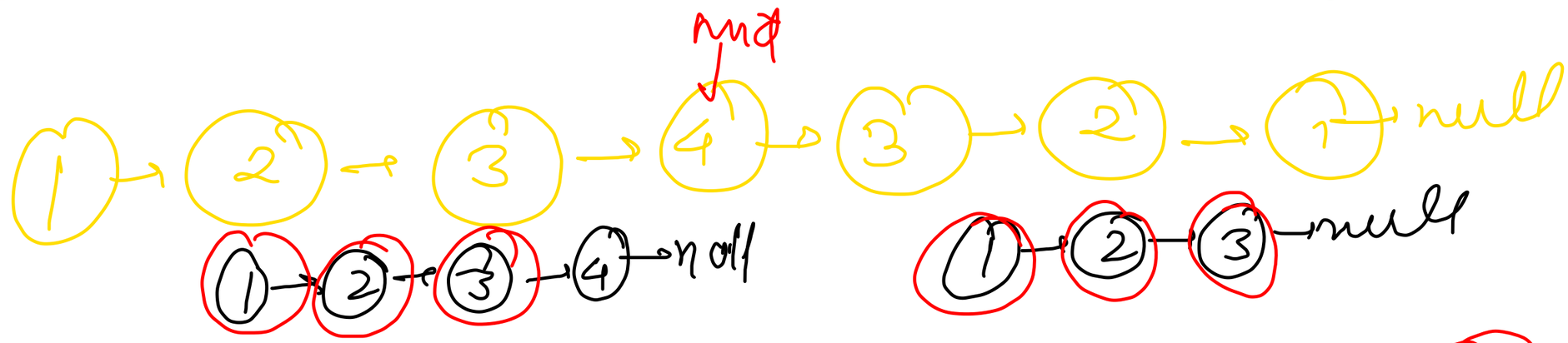
$k = \cancel{6}\ \cancel{5}\ \cancel{4}\ \cancel{3}\ \cancel{2}\ 1 \Rightarrow -1$

⇒ only fast became null

Palindrome LL

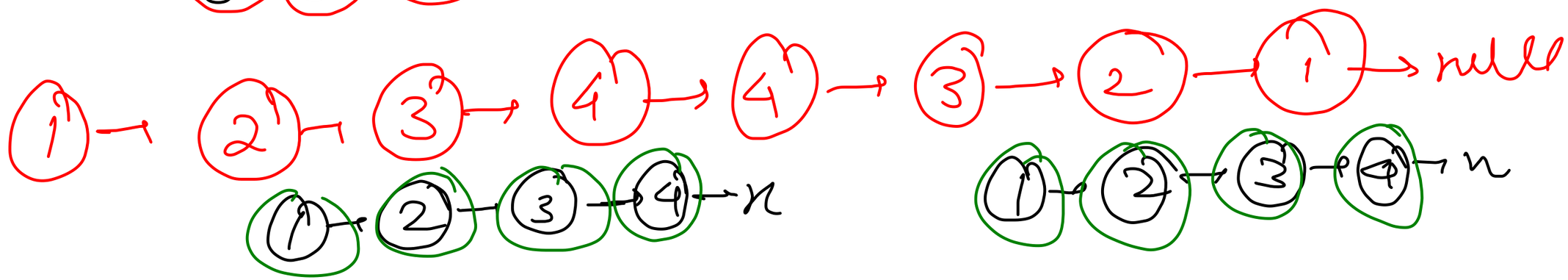
HINT → Reverse LL
→ Middle of LL

Odd:

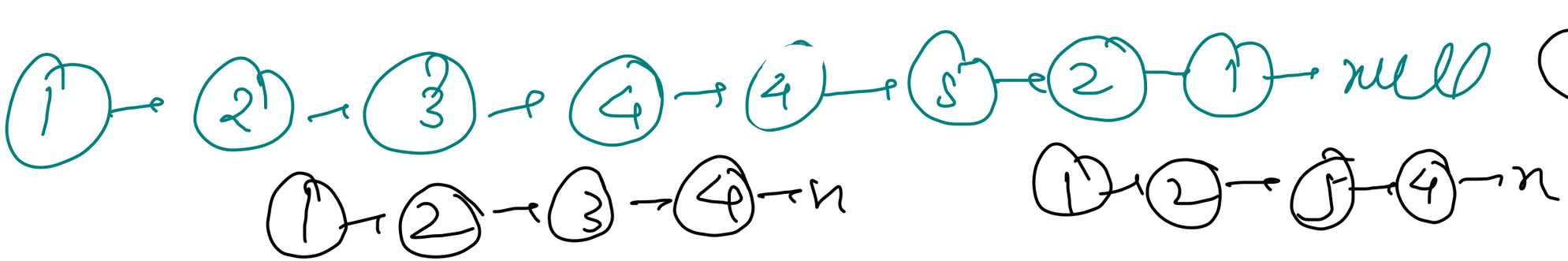


T

Even



T



F

Approach

1. Find Middle Node
2. Reverse the 2nd part
3. Compare both the parts
   - ↳ equal
     - Y → Palindrome (T)
     - N → Palindrome (F)

O(N)

```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;
}
```

Pointer Iterative

O(N)

```java
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;
}
```

even ⇒ first mid
Odd ⇒ Single mid

O(N)

```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;
}
```

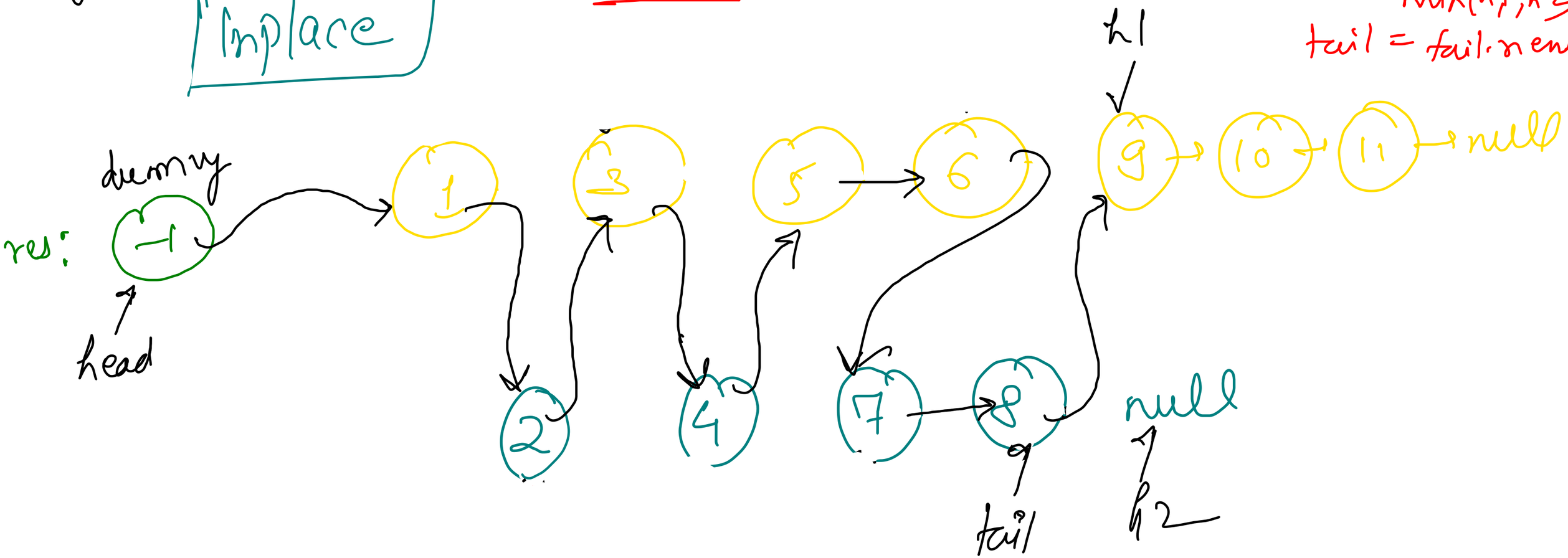
Corner case

Merge 2 sorted lists

$\boxed{\text{Inplace}}$

$O(N+M)$

tail.next = min(h1, h2)
tail = tail.next



```java
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;
}
```

Lecture 24

{Thursday}

→ merge LL

→ merge 2 Sorted LC 21

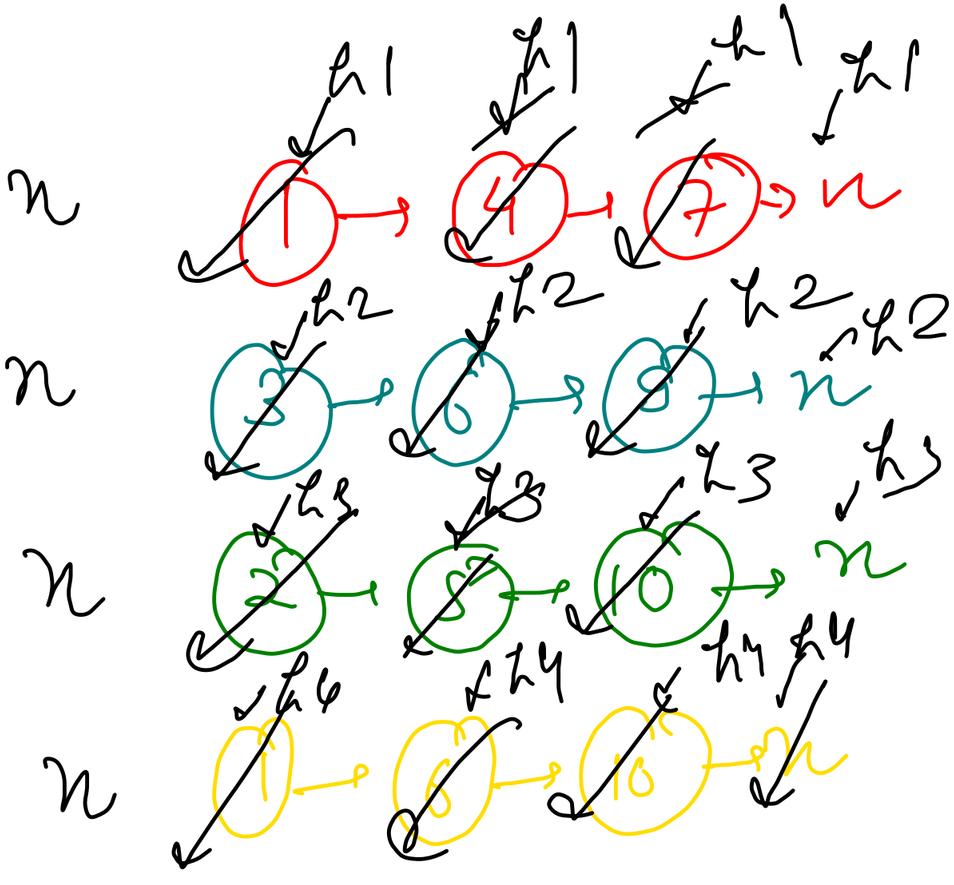
→ merge K Sorted LC HARD 23

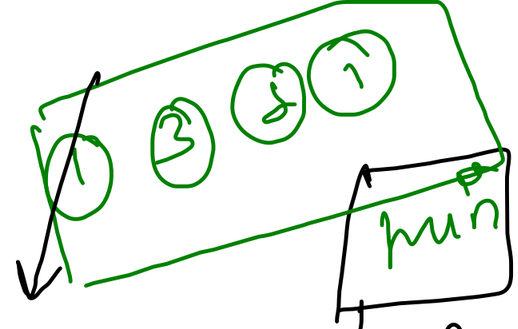
→ merge Sort LC 148

→ Remove Duplicates (1&11) LC 83 & 82

→ Fold & unfold LL LC 143 & Pepcoding

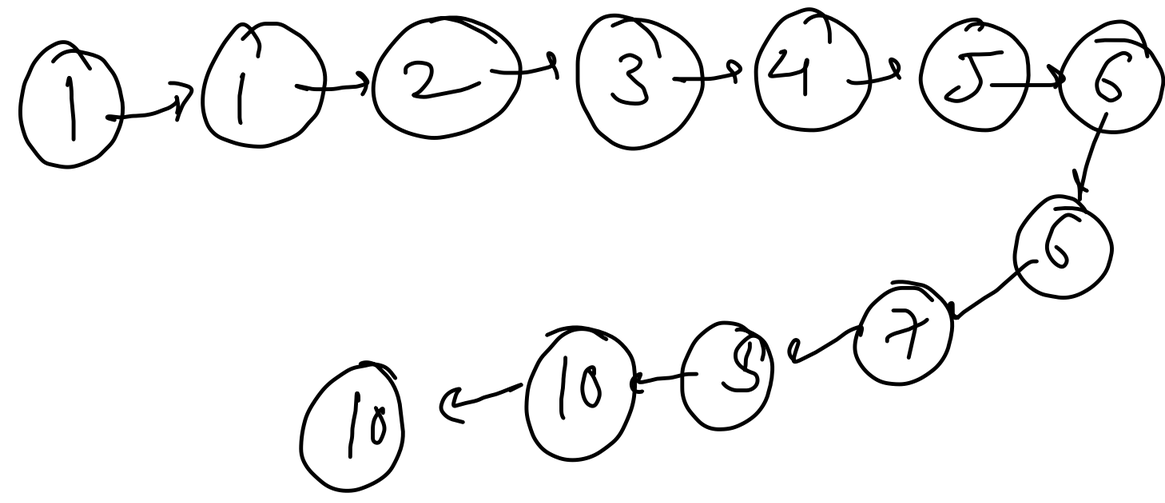
Merge k sorted LL {HARD}





⇒ k elements
⇒ O(k) time

→ in each iteration



resultant node of ndly $N = n * k$ ← number of hl

(12) (3) (4)

↑ node in 1 LL

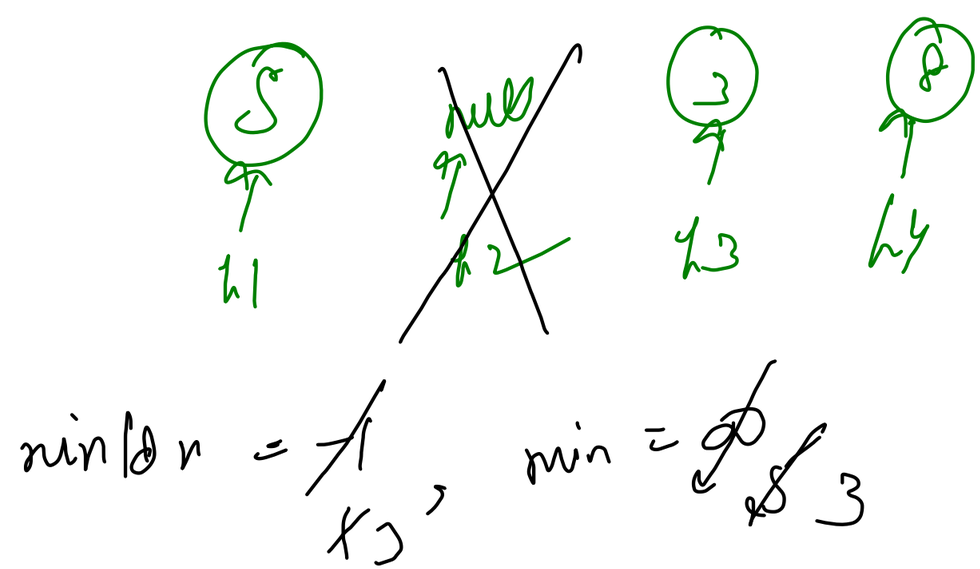
Brute force $\boxed{O(n * k^2)}$

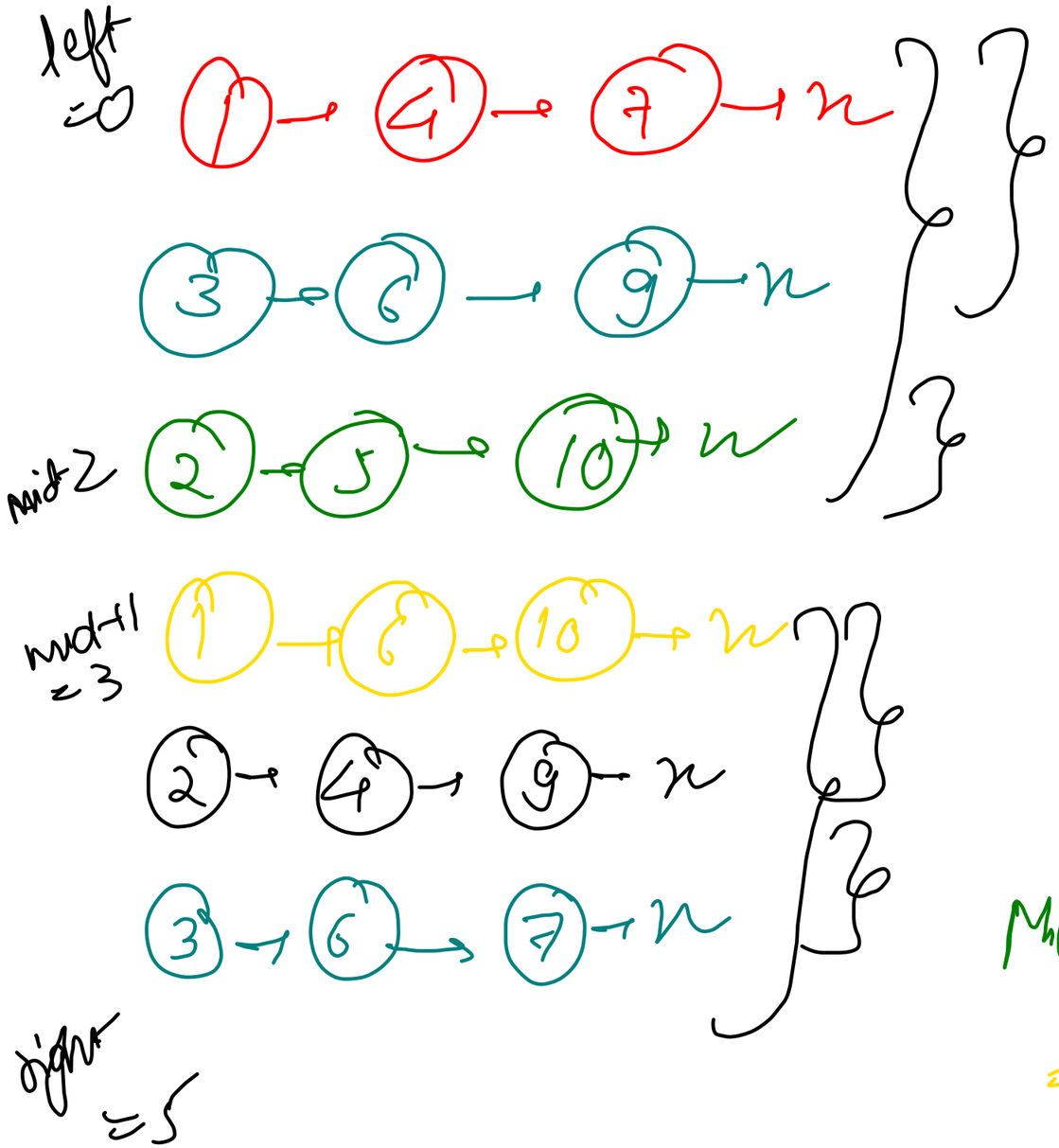
$\boxed{\text{or } O(N * k)}$

Brute force $O(n*k^2) = O(N*K)$

```java
public ListNode mergeKLists(ListNode[] lists) {
    if(lists.length == 0) {
        // 0 linked lists
        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;
}
```

```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;
}
```

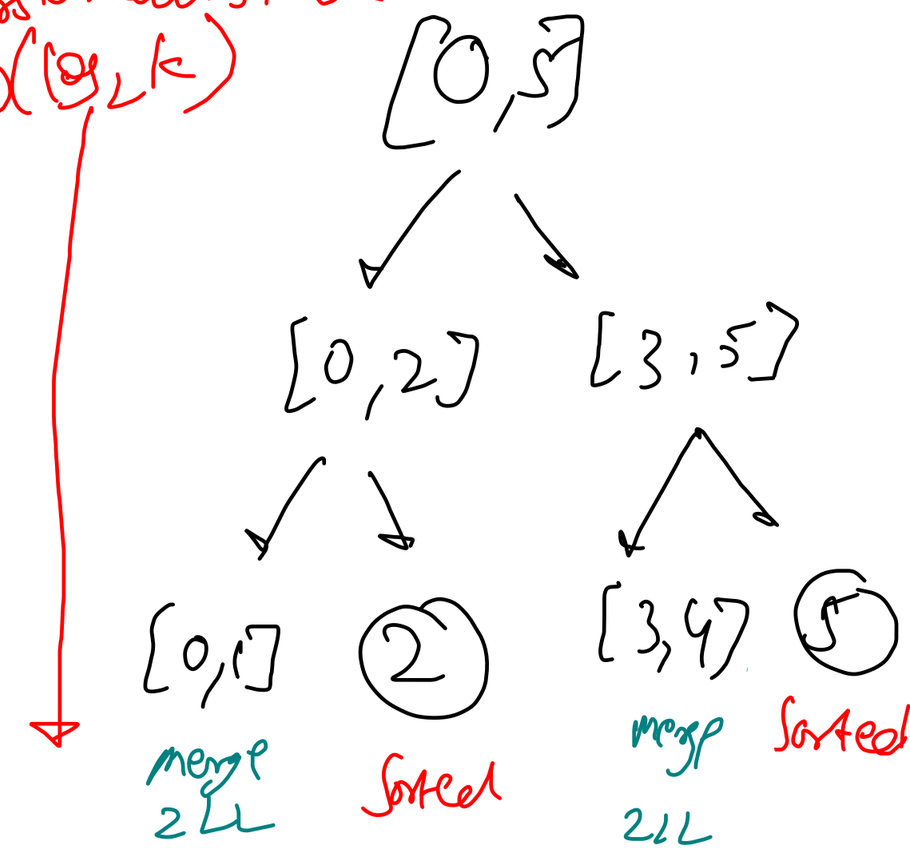




10:10

Recursion call stack

$O(\log_2 k)$



Merge K Sorted (l, r)

$=$ Merge K Sorted (l, m) + Merge K Sorted $(m+1, r)$

+ Merge 2 LL

```java
ListNode merge2List(ListNode head1, ListNode head2) {⇔}

public ListNode helper(ListNode[] lists, int left, int right){
    if(left > right) return null;
    if(left == right) return lists[left];

    int mid = (left + right) / 2;
    ListNode l1 = helper(lists, left, mid);
    ListNode l2 = helper(lists, mid + 1, right);
    return merge2List(l1, l2);
}

public ListNode mergeKLists(ListNode[] lists) {
    if(lists.length == 0) {
        // 0 linked lists
        return null;
    }

    return helper(lists, 0, lists.length - 1);
}
```

divide & conquer

$$T(k) = k * T(0) + k * n * \boxed{\log_2 k}$$

no of terms

$$O(k * n * \log_2 k)$$

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

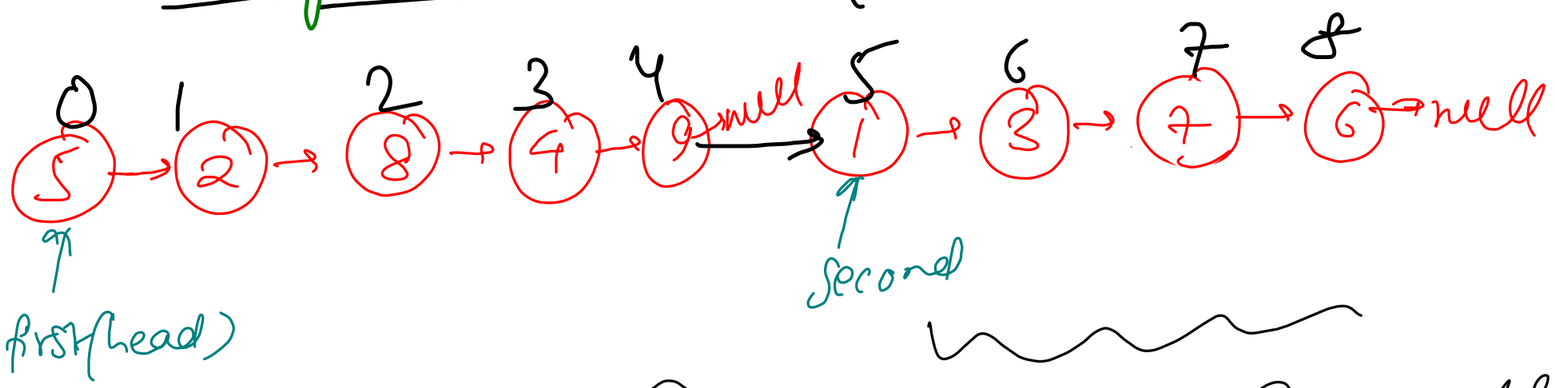
$$T(k/2) = 2T(k/4) + \left(\frac{k}{2} * n\right) * 2^1$$

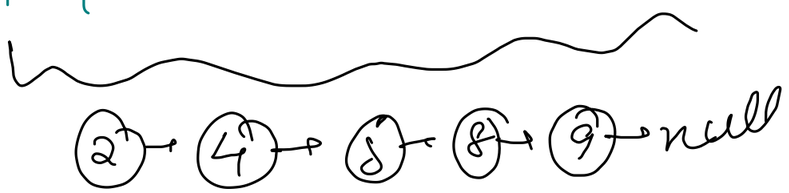
$$T(k/4) = 2T(k/8) + \left(\frac{k}{4} * n\right) * 2^2$$

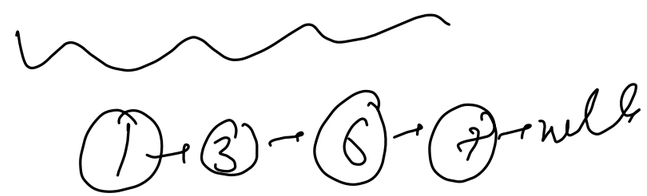
$$\vdots$$

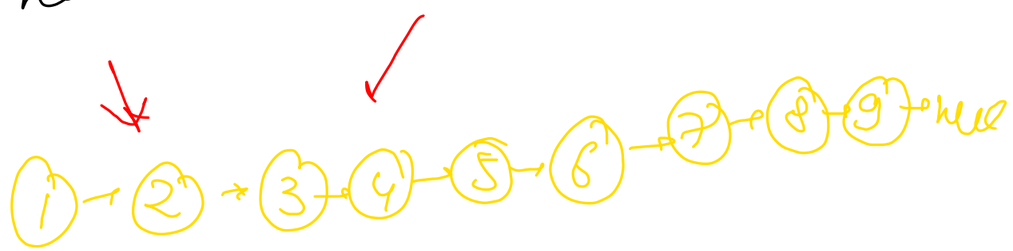
$$T(1) = 2T(0) + \left(\frac{k}{k} * n\right) * 2^{\log_2 k}$$

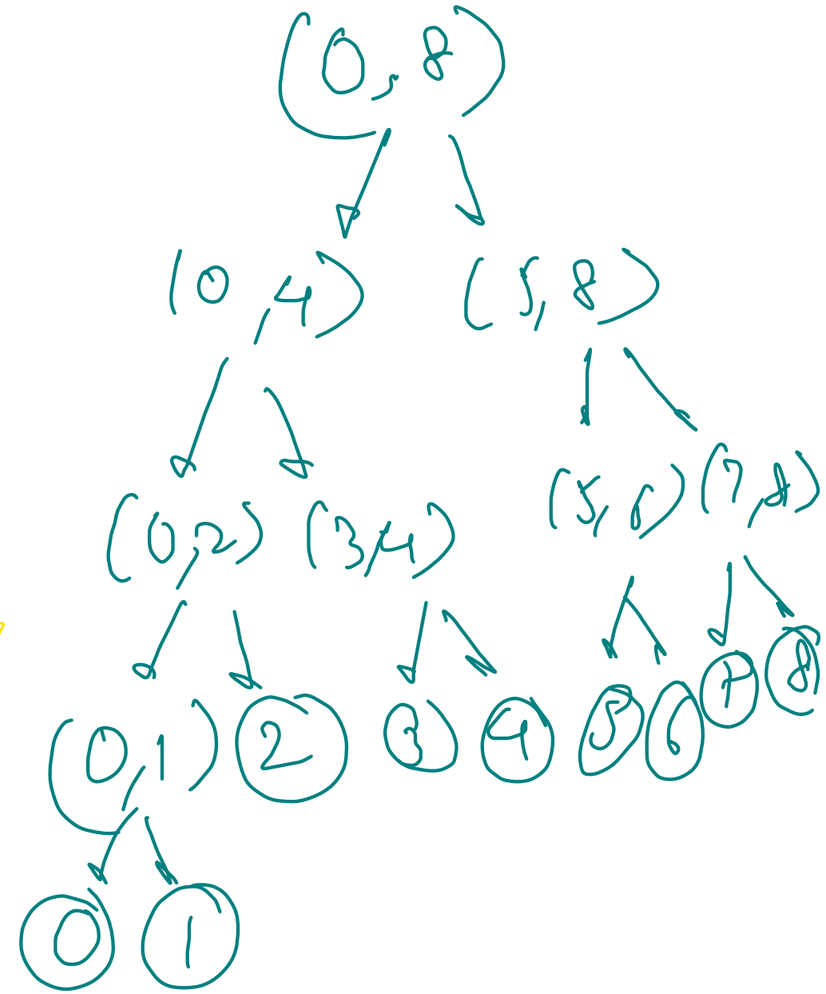
Merge Sort LL {148 LC}











Approach

Merge Sort(LL) →

(1) Find middle & break LL into 2 parts

(2) mergeSort(left)
mergeSort(right)

(3) Merge & Return

```java
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; // odd
}
```

```java
ListNode merge2list(ListNode head1, ListNode head2) {⟺}

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

    ListNode mid = middle(head);
    ListNode midNext = mid.next;
    mid.next = null;

    ListNode left = sortList(head);
    ListNode right = sortList(midNext);
    return merge2list(left, right);
}
```

mergeSort middle Recursive calls merge

$$T(n) = O(n) + 2T(n/2) + O(n)$$

$$T(n) = 2T(n/2) + 2 * O(n) \Rightarrow \boxed{O(n \log_2 n)}$$

MS on LL = MS on Array (in Time Comp)

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

TC: $O(n\log n)$ SC: $O(1)$

merge sort on LL

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

Recursion call stack $\Rightarrow O(\log_2 n)$

merge 2 List is inplace

→ Big-Integers

→ Add 2 th

→ Subtract 2 th

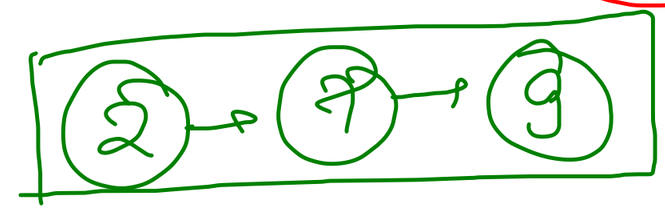
→ Multiply 2 th

int	Long
$2^{31}-1$	$2^{63}-1$
$\approx 10^{9}$	$\approx 10^{18}$

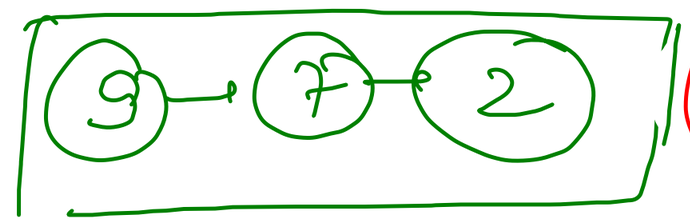
Addition of 2 LL

LC 2 LC 445

972 →

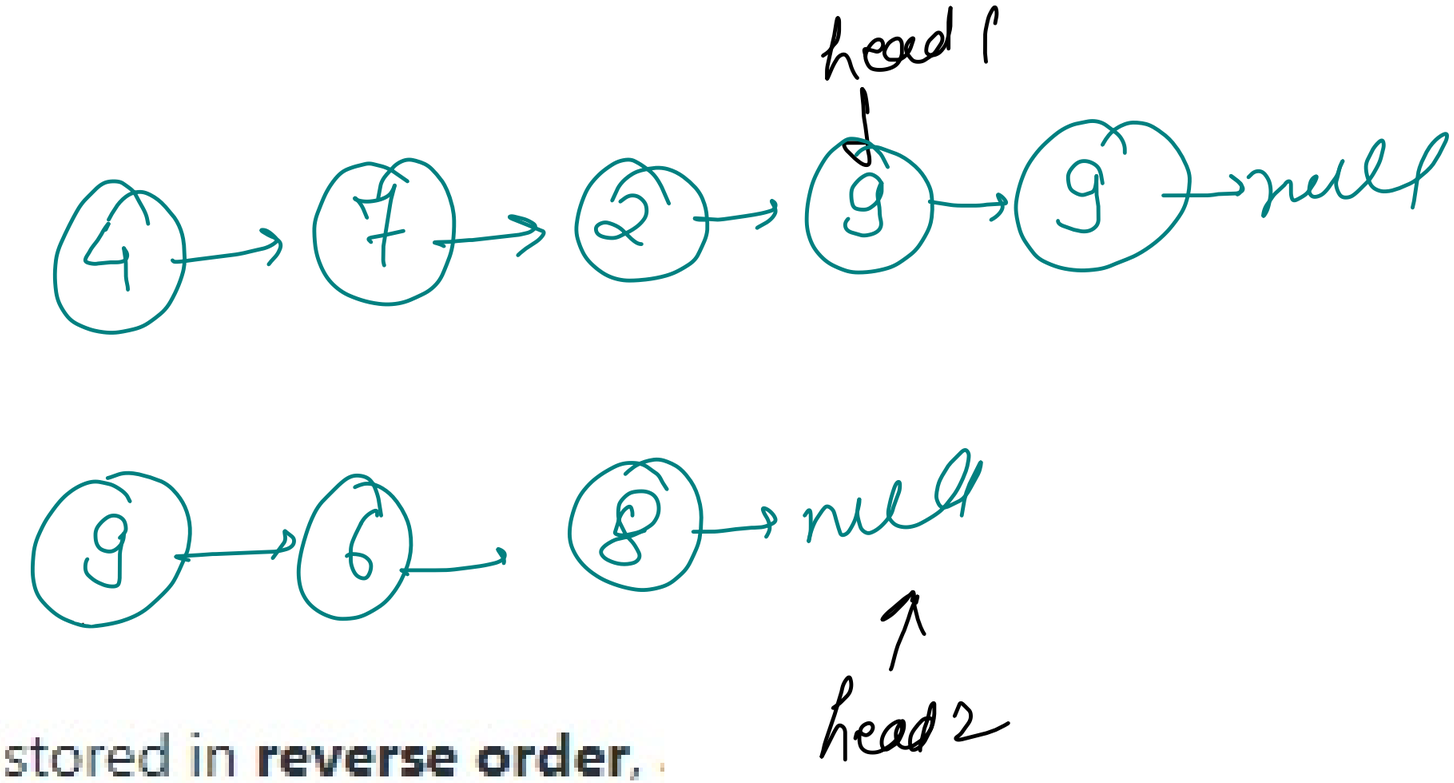


(LC 2)



(LC 445)

LC 2

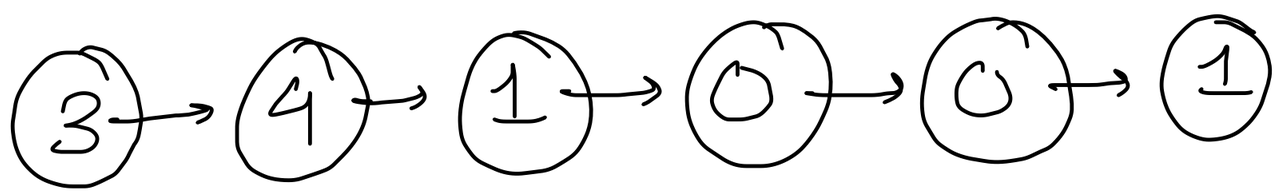


$c = \phi$ 1/0

$$\begin{array}{r} 99274 \\ + \\ 869 \\ \hline 100143 \end{array}$$

The digits are stored in **reverse order**,

ans:



$(d1+d2+c)\%10$ ans

$(d1+d2+c)/10$ carry

```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;
}
```

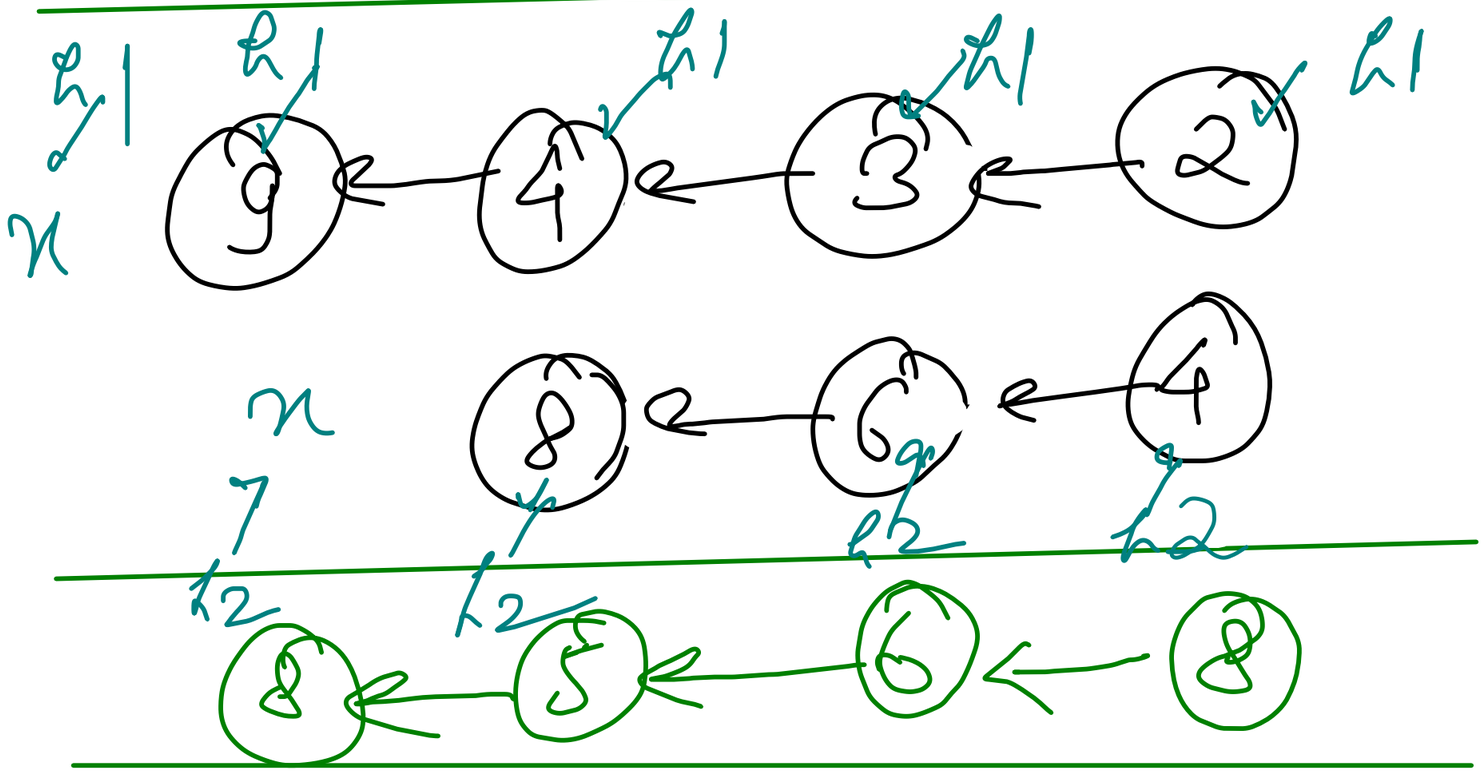
Getting Started

LC 445

```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);
}
```

```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;
}
```

Subtraction in linked list



linked list

Lecture 5

→ Floyd's cycle

→ Cycle Detection

→ Starting pt of cycle

→ Mathematical Proof

→ Insertion Node

→ Clone ll

→ with extra space

→ w/o extra space

Level 2

FJP ↔ JSP

M, T, W, F → DSA level 1

Thurs, weekend → Dev

DSA

Thurs

Sat (2 classes)

Sun (2 classes)

SD ✗

S&S 3-6, 9-12

LL → 1/2

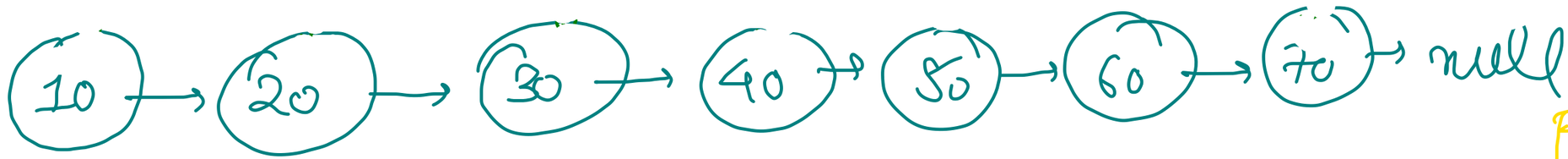
Wed → Resume Review

SQL → level 1

Floyd's cycle Detection

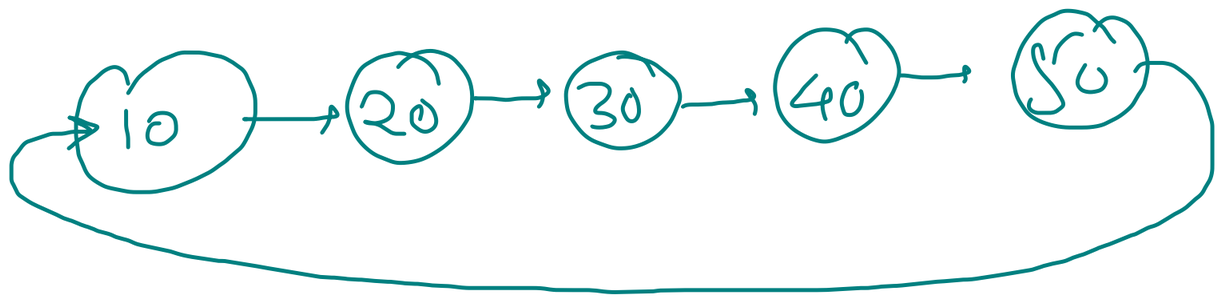
LC 141

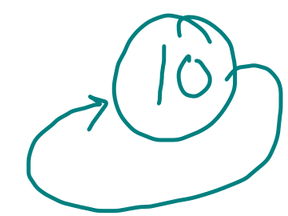
case 1)
SLL



False

case 2)
CSLL

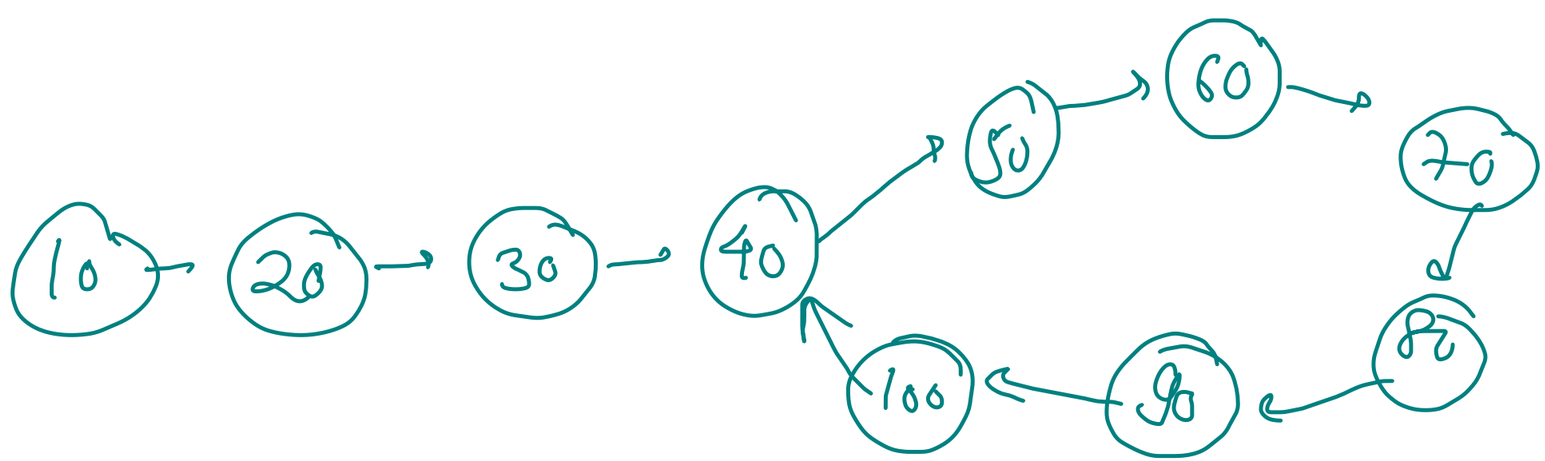




True

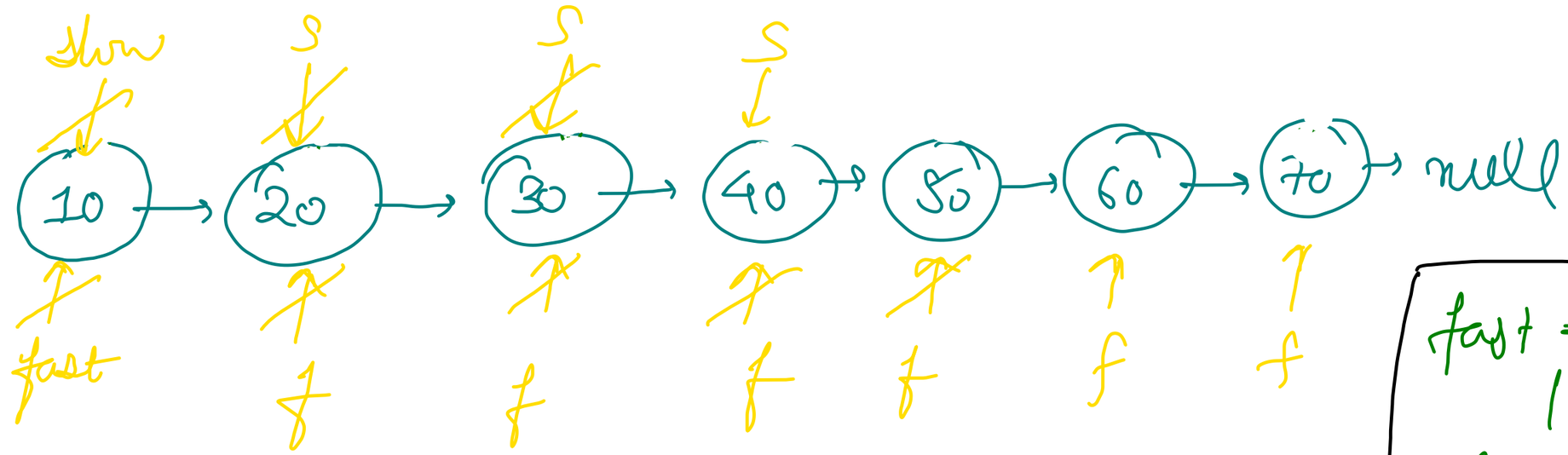
Case 3)

SLL Tail
+
Loop



True

case 1)
SLL

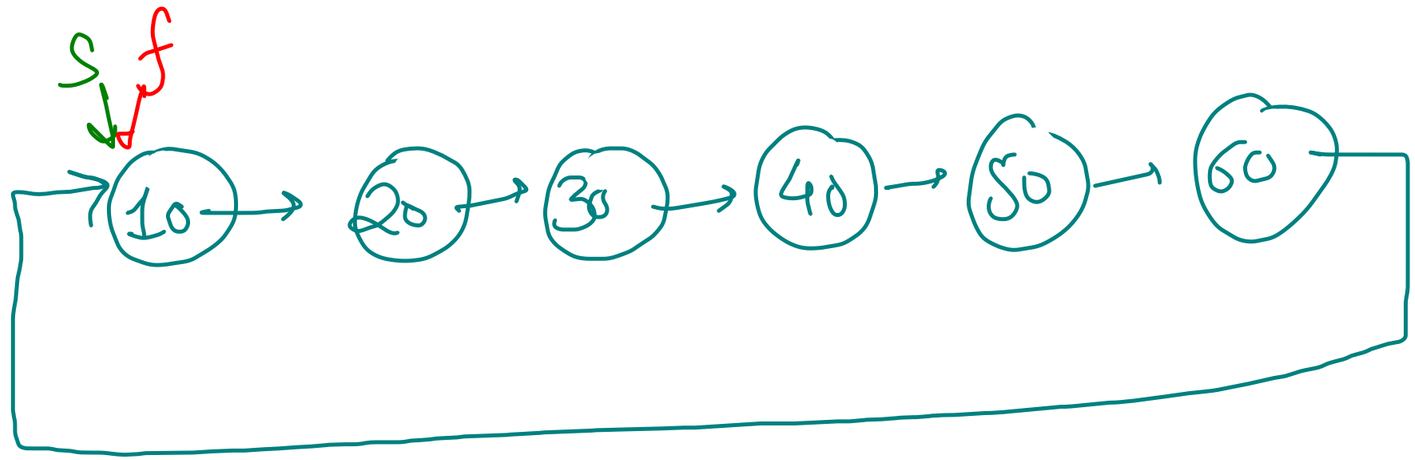


fast == null
||
fast.next
== null

false
(no cycle)

case 2)

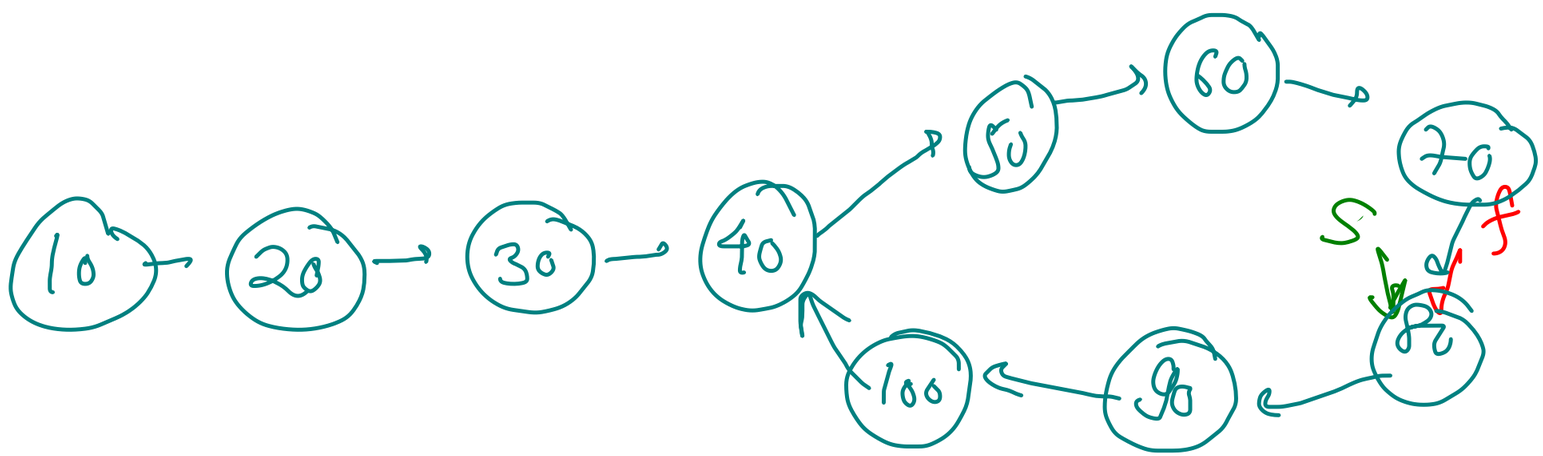
CSLL



True

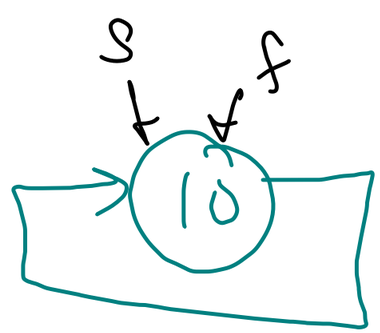
case 3)

Tail + loop



True

Corner case



True

Corner case

0 nodes

head = tail = null

false

```java
public boolean hasCycle(ListNode head) {
    if(head == null || head.next == null) // 0 Nodes or 1 Node
        return false;
    if(head.next == head)
        return true; // Self Referential Node

    ListNode slow = head, fast = head;

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

        if(slow == fast) return true; // Cycle Detected
    }

    return false; // Cycle Not Detected
}
```

O(N) time

- SLL
- CSLL
- Tail + loop

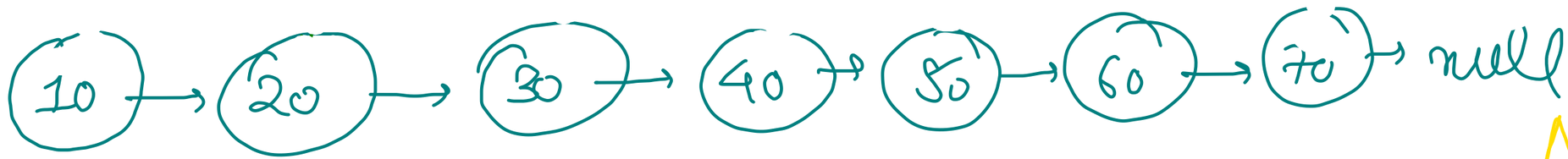
if (slow == head)
CSLL
else tail + loop

O(1) auxiliary space

O(N) input space (N nodes)

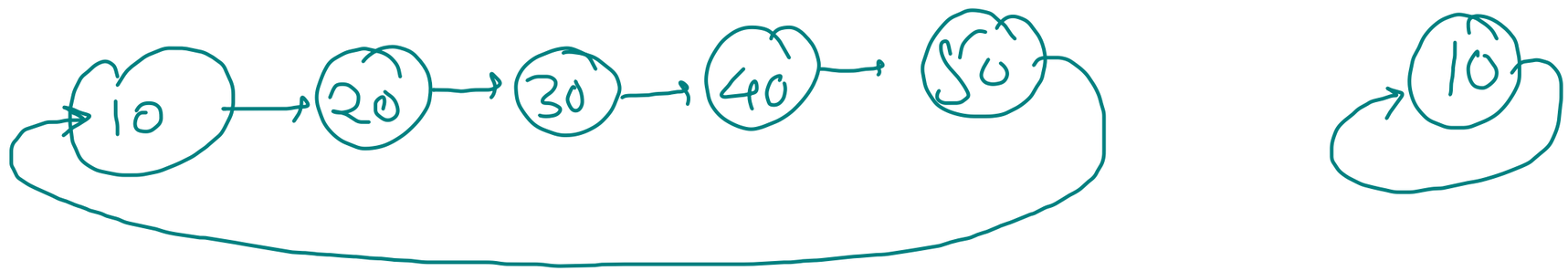
142 Starting Node of Loop

case 1)
SLL



Null

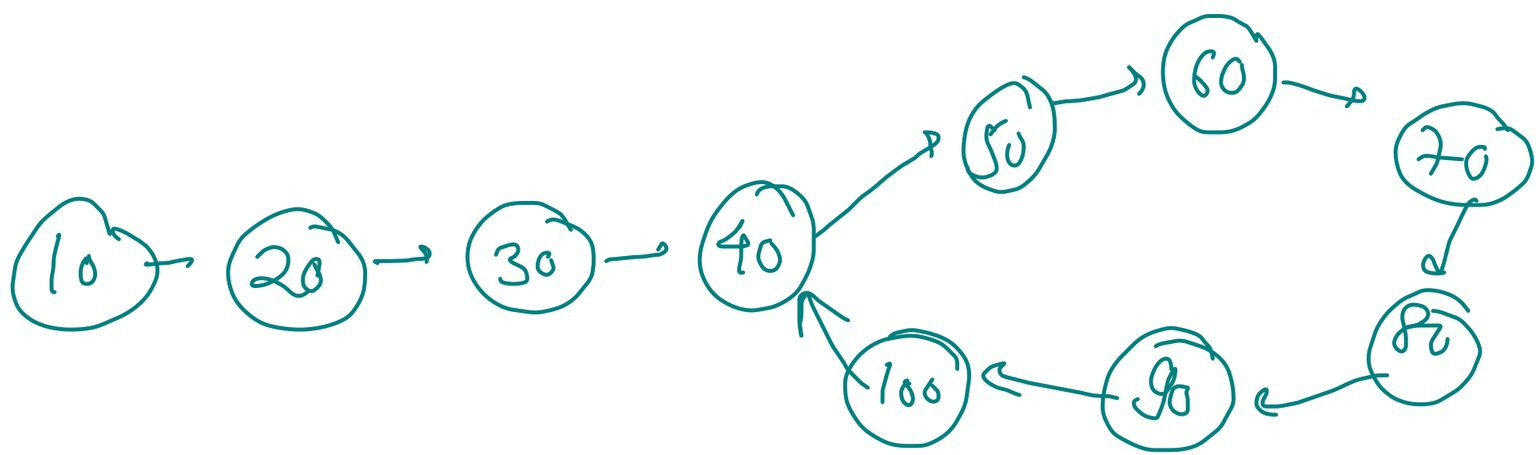
case 2)
CSLL



head 10

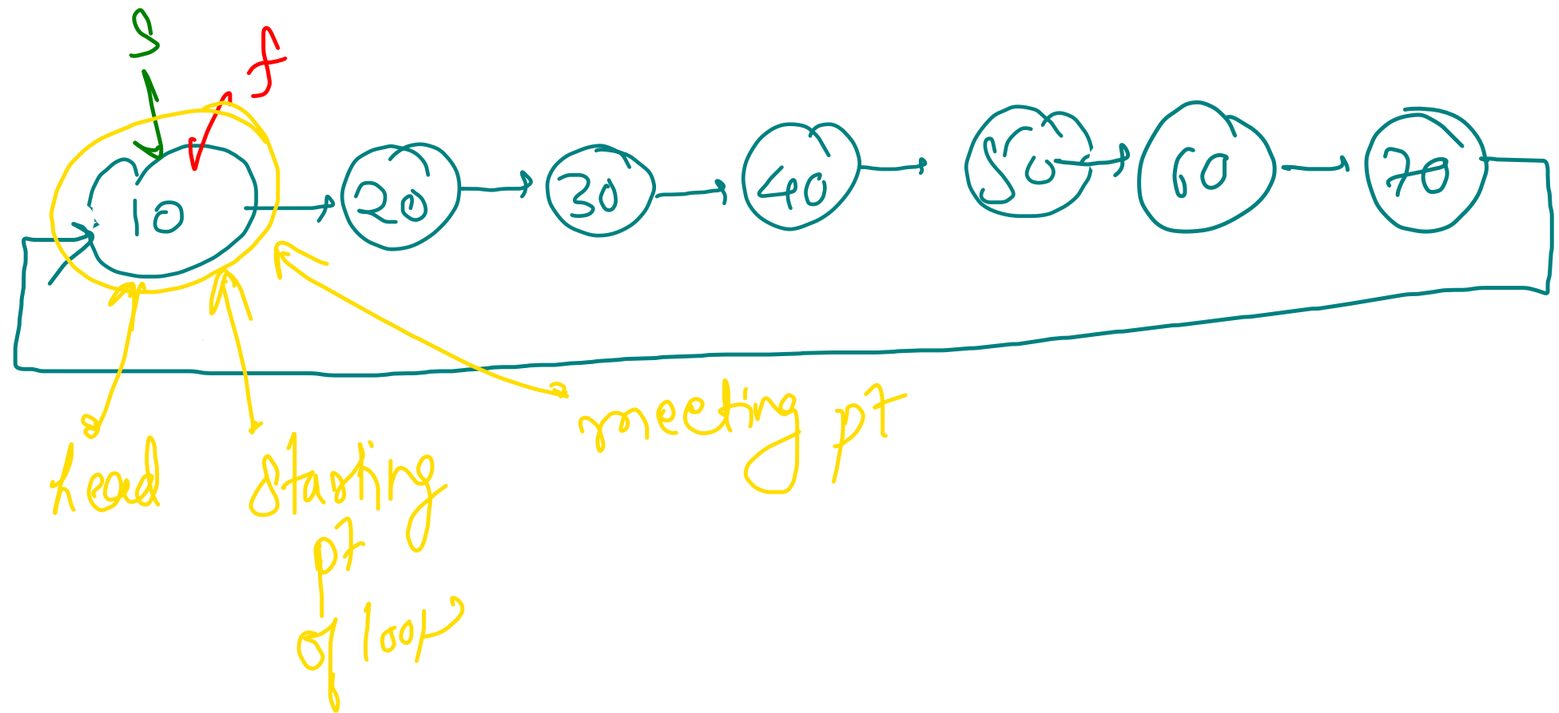
Case 3)

SLL Tail
+
Loop



True
40

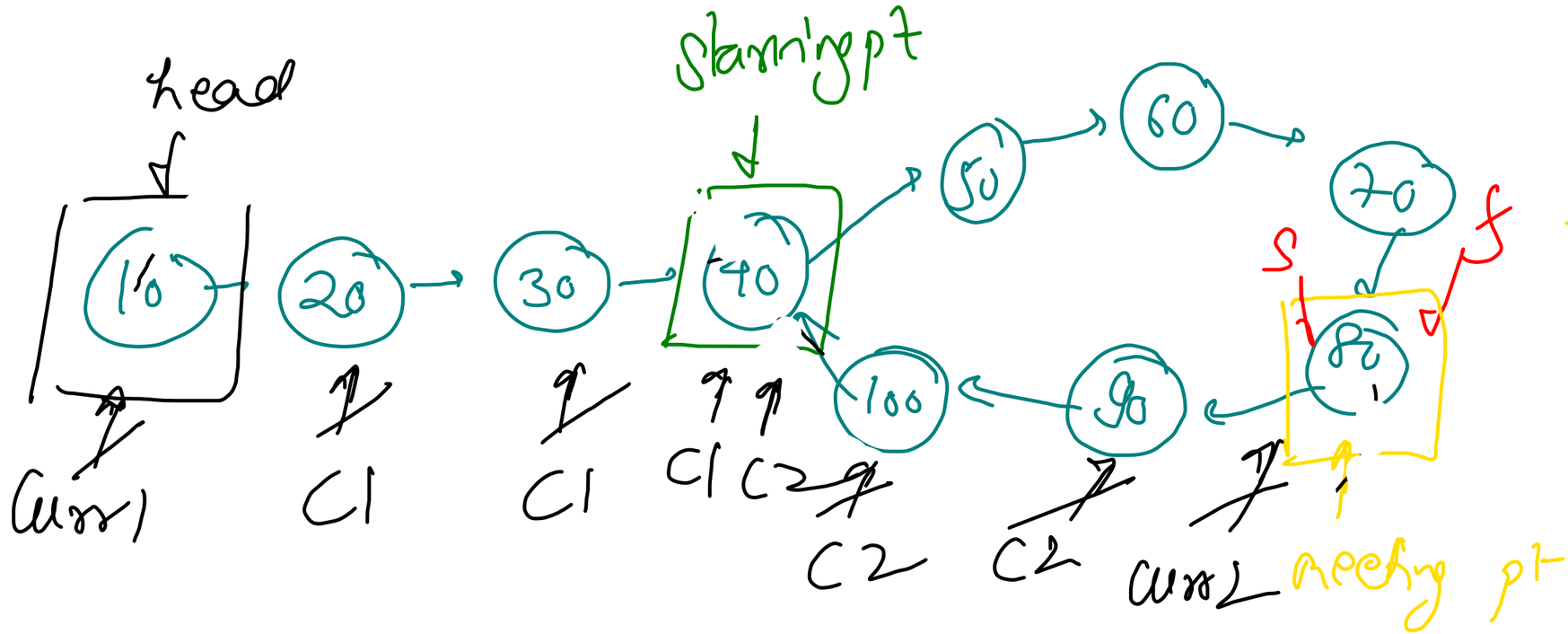
case 2)
CSLL



head 10

Case 3)

SLL Tail + Loop



True

40

Distance b/w starting pt & head is equal to distance b/w starting pt & meeting point

```java
public ListNode detectCycle(ListNode head) {
    ListNode slow = head, 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) SLL
        return null; // no cycle

    ListNode curr1 = head, curr2 = slow;
    while(curr1 != curr2){
        curr1 = curr1.next;
        curr2 = curr2.next;
    }

    return curr1;
}
```

O(N)

NO loop

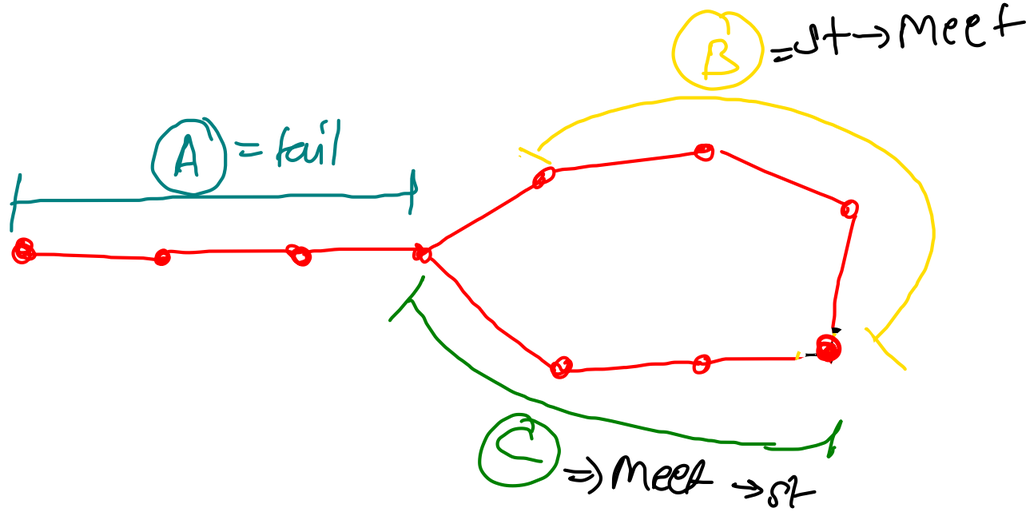
loop detected

O(N)

Dist b/w

H & S = M & S

Mathematical Proof



slow = 1 node / itr

fast = 2 node / itr

Total time taken by slow = Total time taken by fast

$$\frac{d_{slow}}{\text{speed}_{slow}} = \frac{d_{fast}}{\text{speed}_{fast}}$$

ss sf

$$\frac{A + (B+C)i + B}{ss} = \frac{A + (B+C)j + B}{sf}$$

length of loop = (B+C)

length of tail = (A)

No of rotation taken by slow = i

No of rotation taken by fast = j

ss = speed of slow

sf = speed of fast

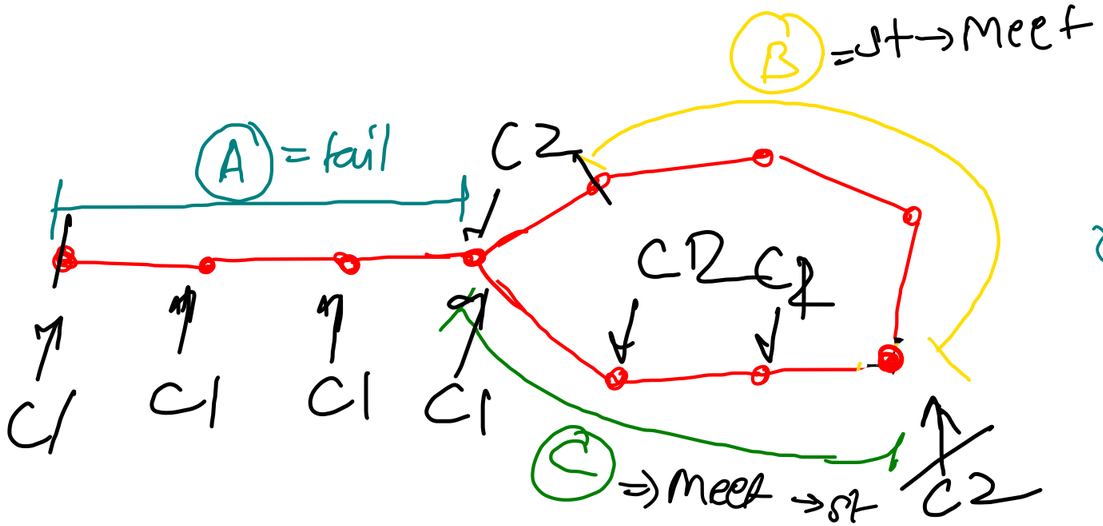
$$\frac{d_{slow}}{speed_{slow}} = \frac{d_{fast}}{speed_{fast}}$$

ss sf

$$\frac{A + (B+C)i + B}{ss} = \frac{A + (B+C)j + B}{sf}$$

relative speed of fast wrt slow $= \gamma$

$$\boxed{\frac{sf}{ss}} \left\{ A + (B+C)i + B \right\} = A + (B+C)j + B$$



$$\gamma A + \gamma(B+C)i + \gamma B = A + (B+C)j + B$$

$$\gamma A + \gamma B - A - B = (B+C)(j - \gamma i)$$

$$(\gamma - 1)A + (\gamma - 1)B = (B+C)(j - \gamma i)$$

$$(\gamma - 1)(A+B) = B+C\,(j - \gamma i)$$

$$A+B = B+C\left\{\boxed{\frac{j - \gamma i}{\gamma - 1}}\right\}$$

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

tail

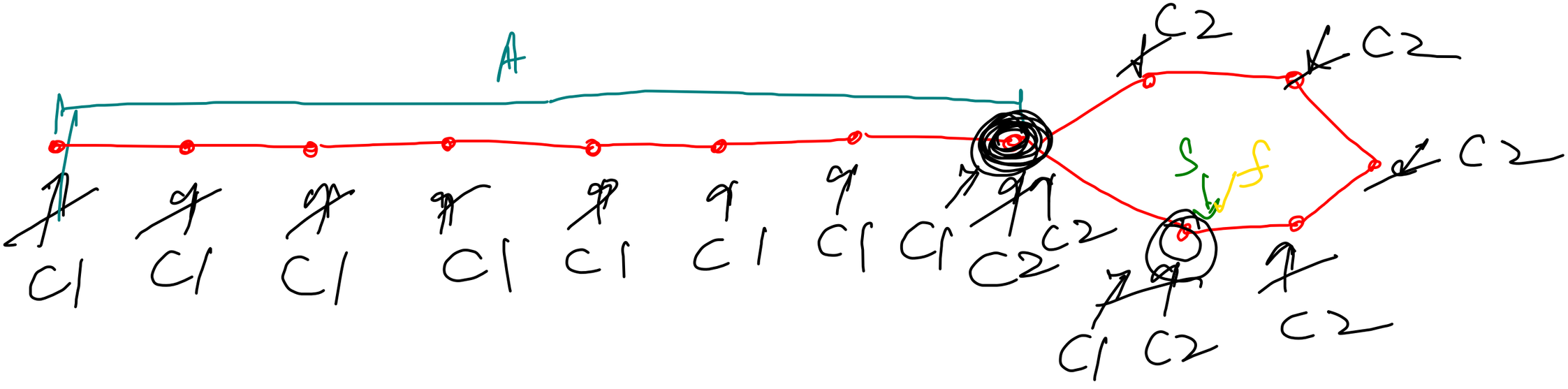
Some cycles − B

C1 1 m/s

A → A sec

C2 1 m/s

Cycles − fall short of



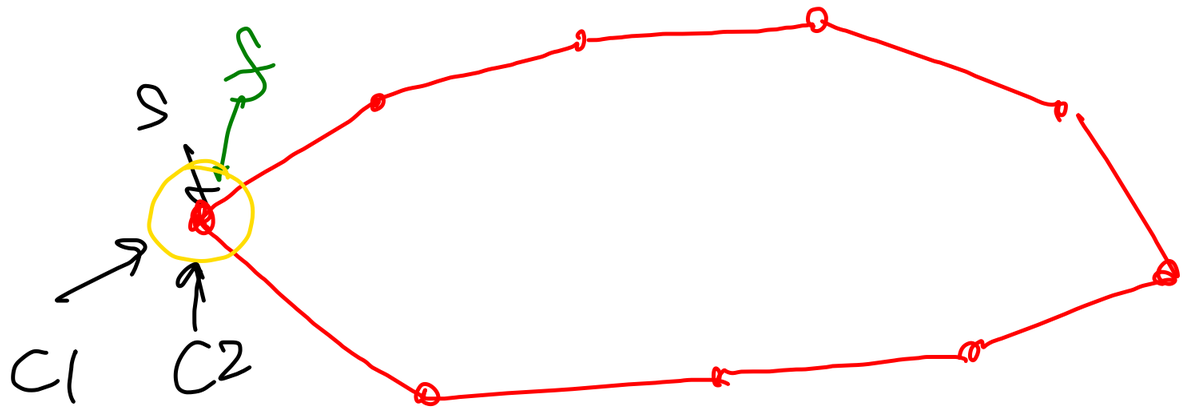
$$A = (B+C)k - B$$

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

$$A = (B+C)(k'+1) - B$$

$$= (B+C)k' + \cancel{B} + C - \cancel{B}$$

CSLL



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

$$A = \underbrace{(B+C)}_{0}k' + \underbrace{C}_{0}$$

(0)

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

$$\{S_{fast} = 2 * S_{slow}\}$$

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

$$\{t_{slow} = t_{fast}\}$$

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

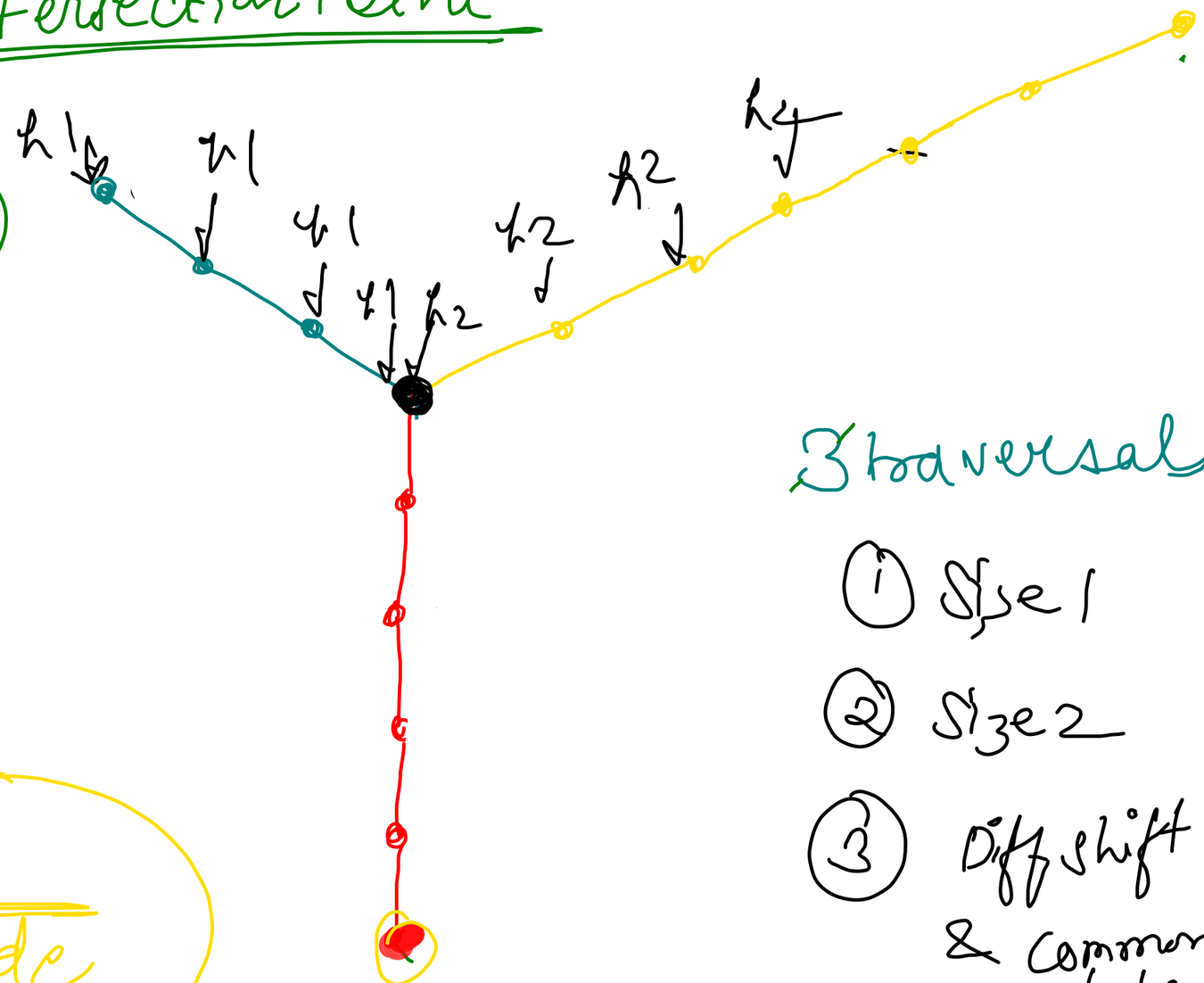
$$A + cycle(j) + B = 2(A + cycle(i) + B)$$

$$A + cj + B = 2A + c2i + 2B$$

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

Intersection Point

size1 = 9



size2 = 12

diff = 12 - 9
= 3

3 traversal

1. Size1
2. Size2
3. Diff shift & common intersection

$x + z = 9 - 5 = 4$

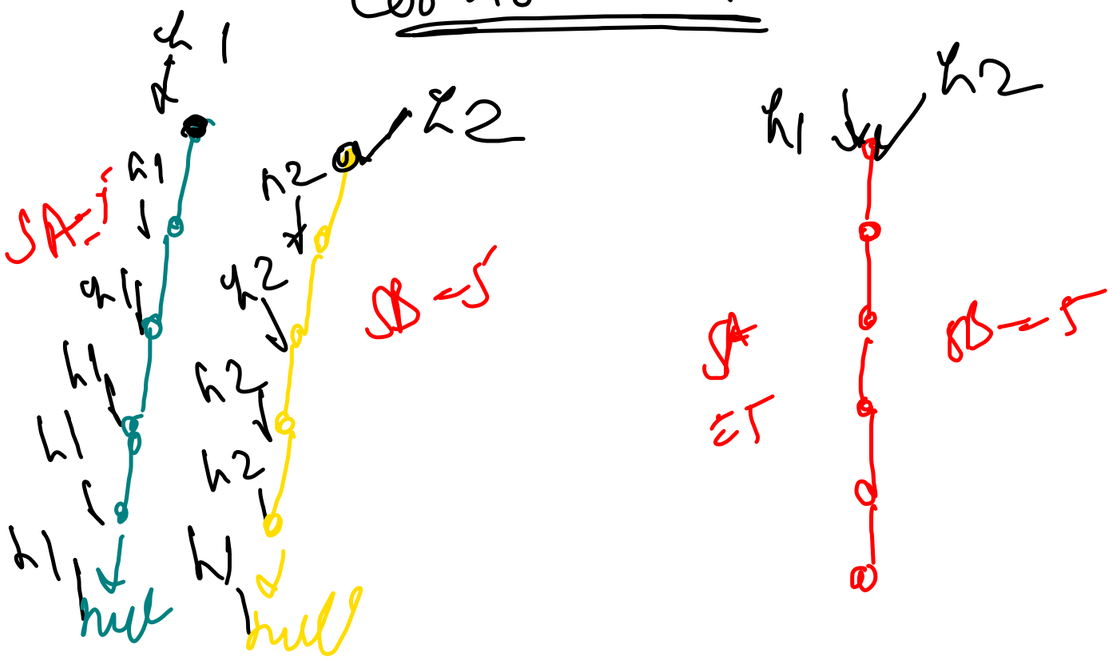
$y + z = 12 - 5 = 7$

160 Leetcode

using floyd's cycle

```
public ListNode detectCycle(ListNode head) {} 142

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;
}
```

Corner cases



① null

② h1==h2

```
public int getSize(ListNode head){
    int size = 0;
    while(head != null){
        head = head.next;
        size++;
    }
    return size;
}
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;
}
```

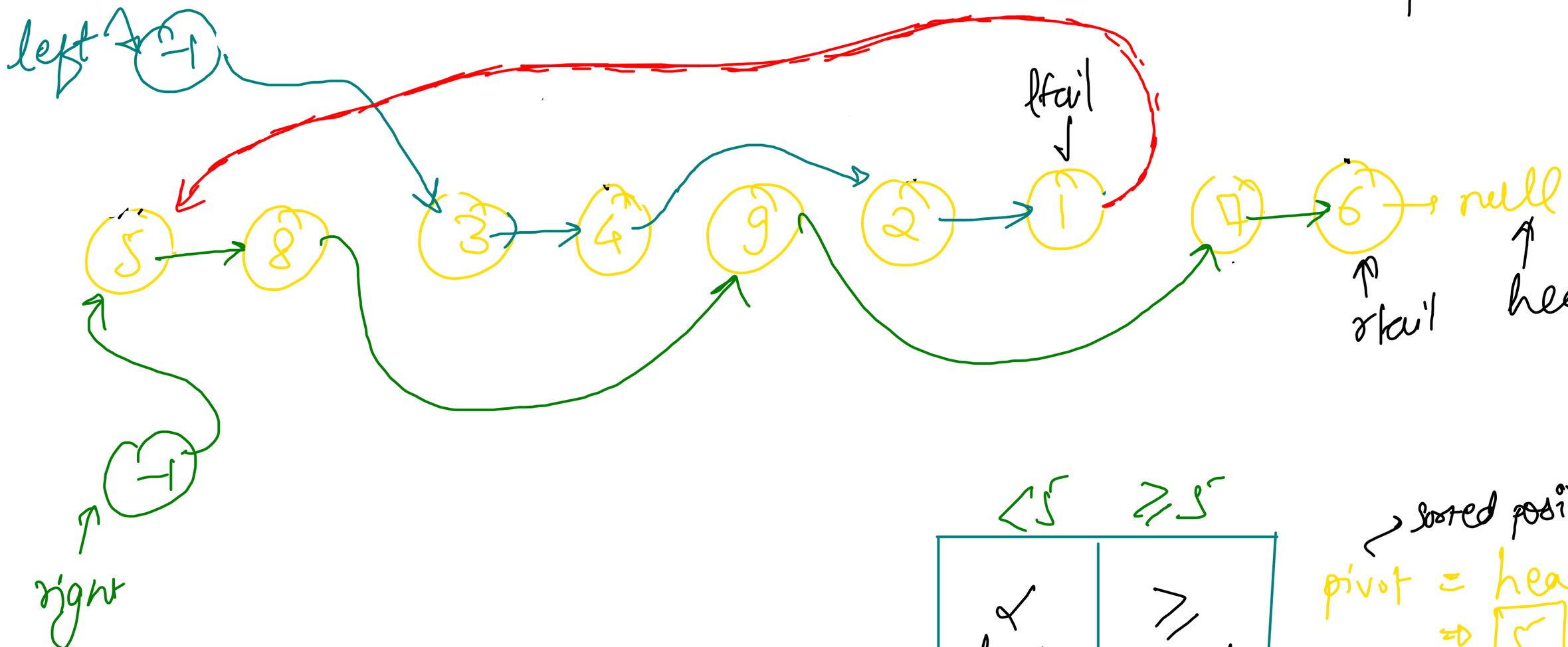
Lecture 6 {3 PM to 6 PM – Sunday}

- → Partition List 86 LC
- → Sort 01 (IB), Sort 012 (GFG)
- → Quick Sort on LL 148 LC

leetcode 86

Partition list → Stable

3, 4, 2, 1, 5, 8, 9, 7, 6



< 5	≥ 5
< left	≥ right

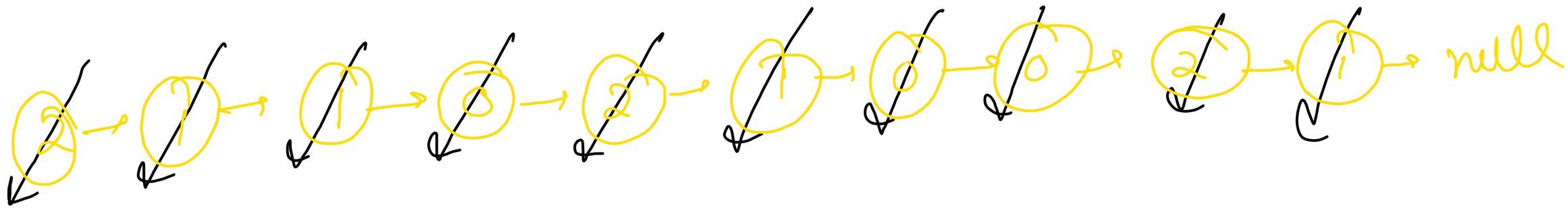
sorted position

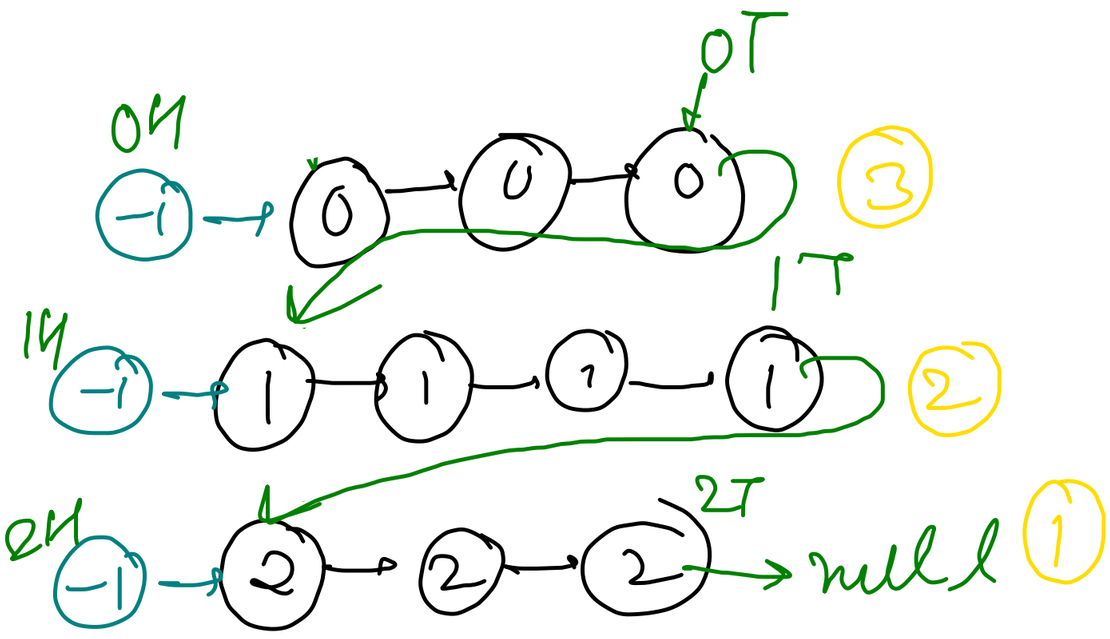
pivot = head

⇒ $\boxed{5}$

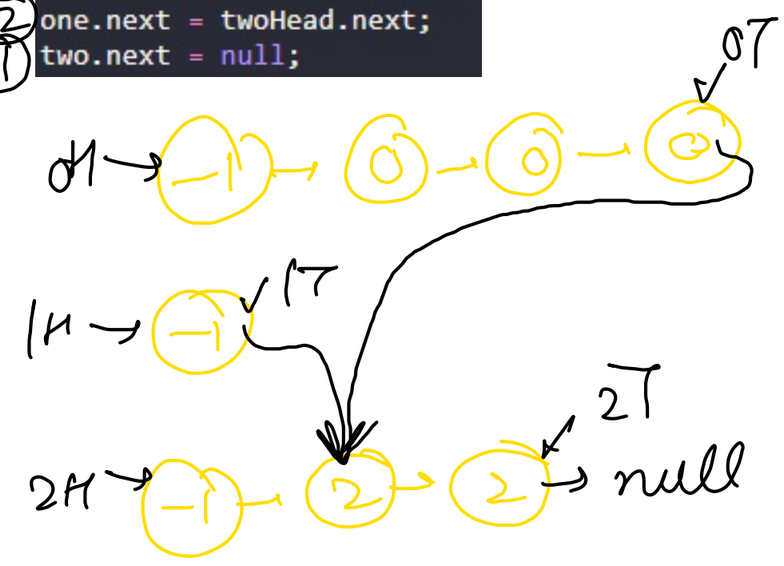
```java
public ListNode partition(ListNode head, int x) {
    ListNode lHead = new ListNode(-1);
    ListNode lTail = lHead;
    ListNode rHead = new ListNode(-1);
    ListNode rTail = rHead;

    while(head != null){
        if(head.val < x){
            lTail.next = head;
            lTail = head;
        } else {
            rTail.next = head;
            rTail = head;
        }
        head = head.next;
    }

    lTail.next = rHead.next;
    rTail.next = null;
    return lHead.next;
}
```

Sort 012





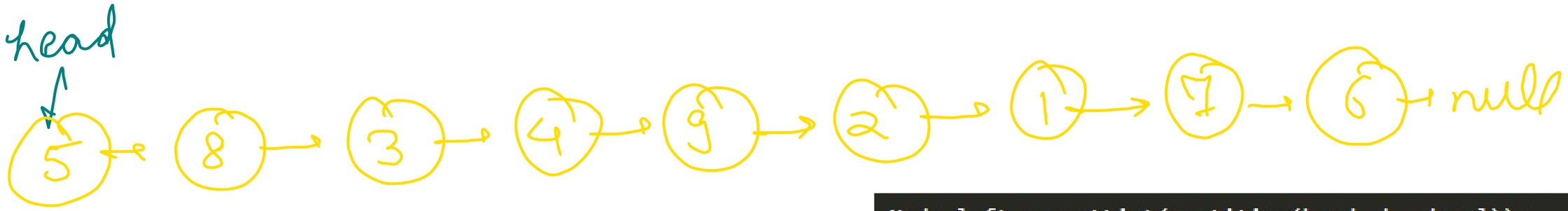

```
zero.next = oneHead.next;
one.next = twoHead.next;
two.next = null;
```



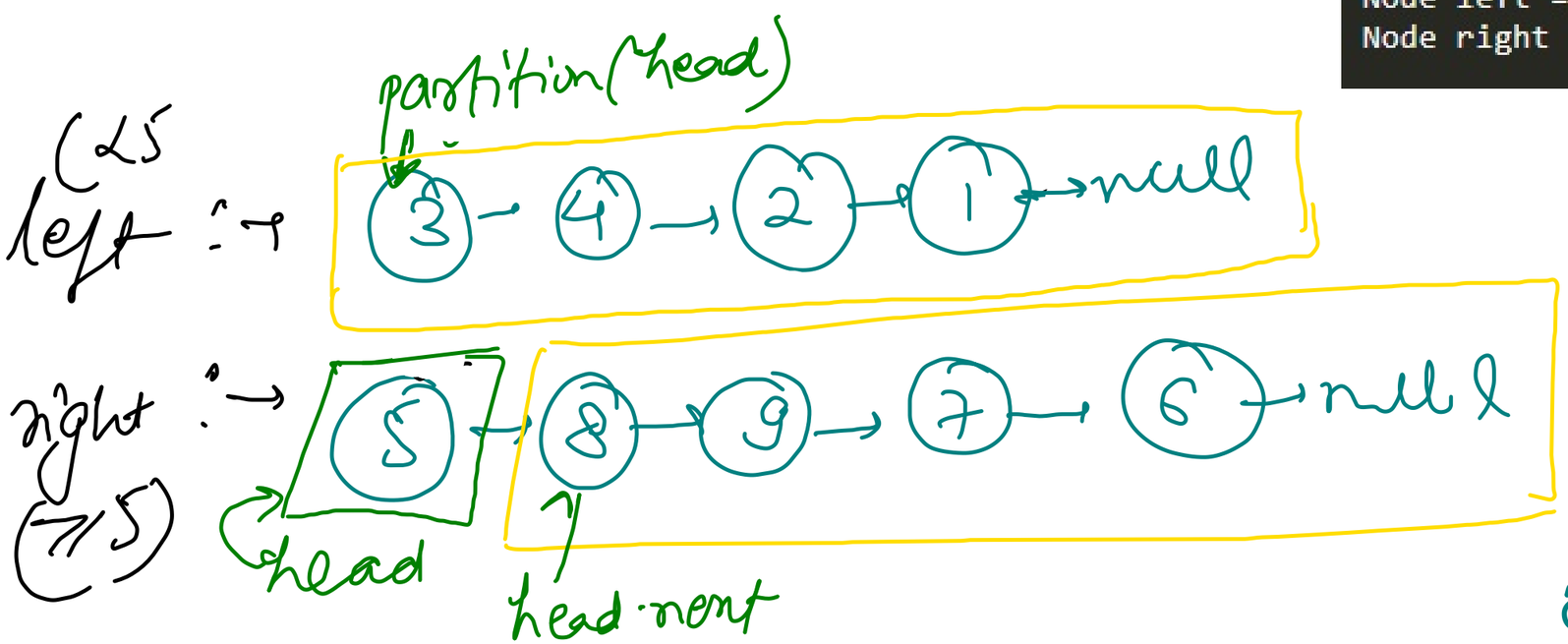
```java
Node zeroHead = new Node(-1);
Node oneHead = new Node(-1);
Node twoHead = new Node(-1);
Node zero = zeroHead, one = oneHead, two = twoHead;

while(head != null){
    if(head.data == 0){
        zero.next = head;
        zero = head;
    } else if(head.data == 1){
        one.next = head;
        one = head;
    } else {
        two.next = head;
        two = head;
    }
    head = head.next;
}

two.next = null;
one.next = twoHead.next;
zero.next = oneHead.next;
return zeroHead.next;
```

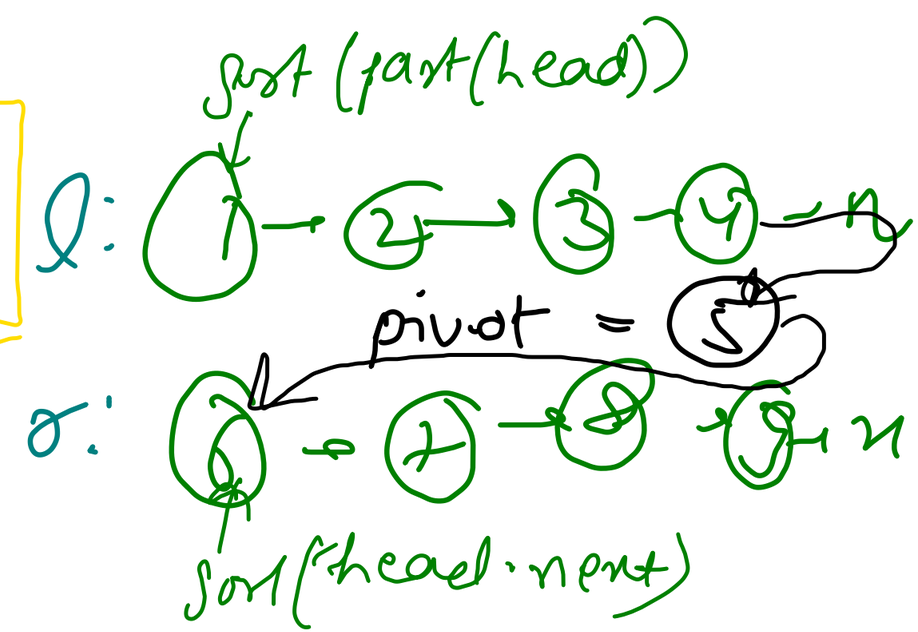
Sort LL using Quick Sort (148)

(3421) (5) (8976)




```
Node left = sortList(partition(head, head.val));
Node right = sortList(head.next);
```





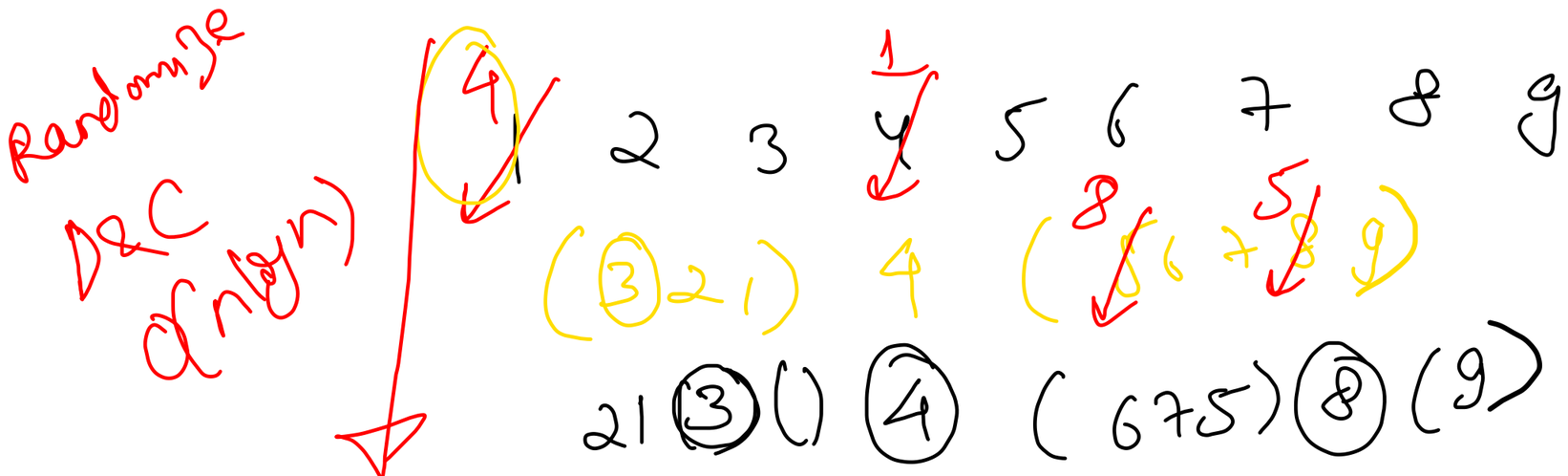
```java
public ListNode partition(ListNode head, int x) {
    ListNode lHead = new ListNode(-1);
    ListNode lTail = lHead;
    ListNode rHead = new ListNode(-1);
    ListNode rTail = rHead;

    while(head != null){
        if(head.val < x){
            lTail.next = head;
            lTail = head;
        } else {
            rTail.next = head;
            rTail = head;
        }
        head = head.next;
    }

    lTail.next = null;
    rTail.next = null;
    return lHead.next;
}
```

```java
public ListNode getTail(ListNode curr){
    if(curr == null) return null;
    while(curr.next != null) curr = curr.next;
    return curr;
}

public ListNode sortList(ListNode head) {
    // base case
    if(head == null || head.next == null){
        return head;
    }
    randomize()
    ListNode left = sortList(partition(head, head.val));
    ListNode right = sortList(head.next);
    head.next = right;

    // left -> pivot (head) -> right
    if(left == null) return head;

    ListNode leftTail = getTail(left);
    leftTail.next = head;
    return left;
}
```

Randomize

D&C

O(nlogn)



```java
public void randomize(ListNode head){
    int size = 0;
    ListNode curr = head;
    while(curr != null){
        size++;
        curr = curr.next;
    }

    int randomIdx = (new Random()).nextInt(size);

    curr = head;
    while(randomIdx-- > 0){
        curr = curr.next;
    }

    int temp = head.val;
    head.val = curr.val;
    curr.val = temp;
}
```

[0, size)

Linked list → Lecture 7 {Monday, 8:30 PM to 12:00 AM}

1. Remove Duplicates → I & II
2. Fold LL, Unfold LL
3. Odd Even LL → Index / Value
4. Rotate list

M, T, W, F ⇒ DSA

Thurs ⇒ DSA contest

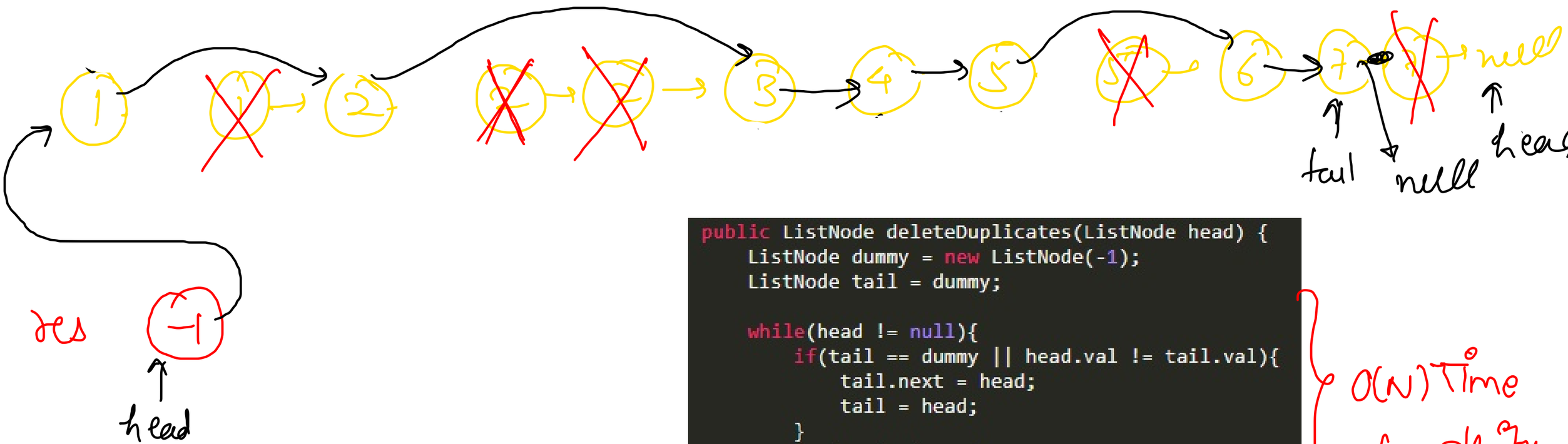
Weekends ⇒ Dev

Weekends + Thurs ⇒ optional 12

Remove Duplicates

83

Sorted LL ⇒ All occurency are consecutive

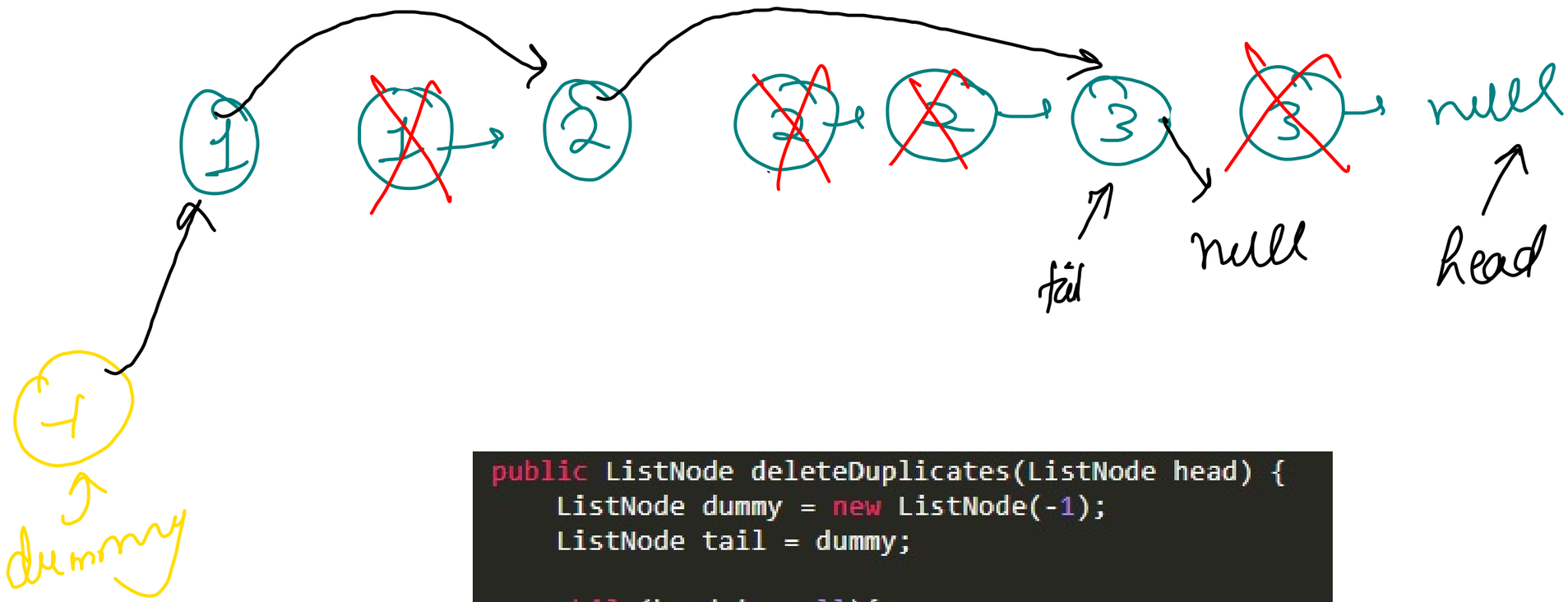


yes

$\boxed{O(1) \text{ extra space}}$

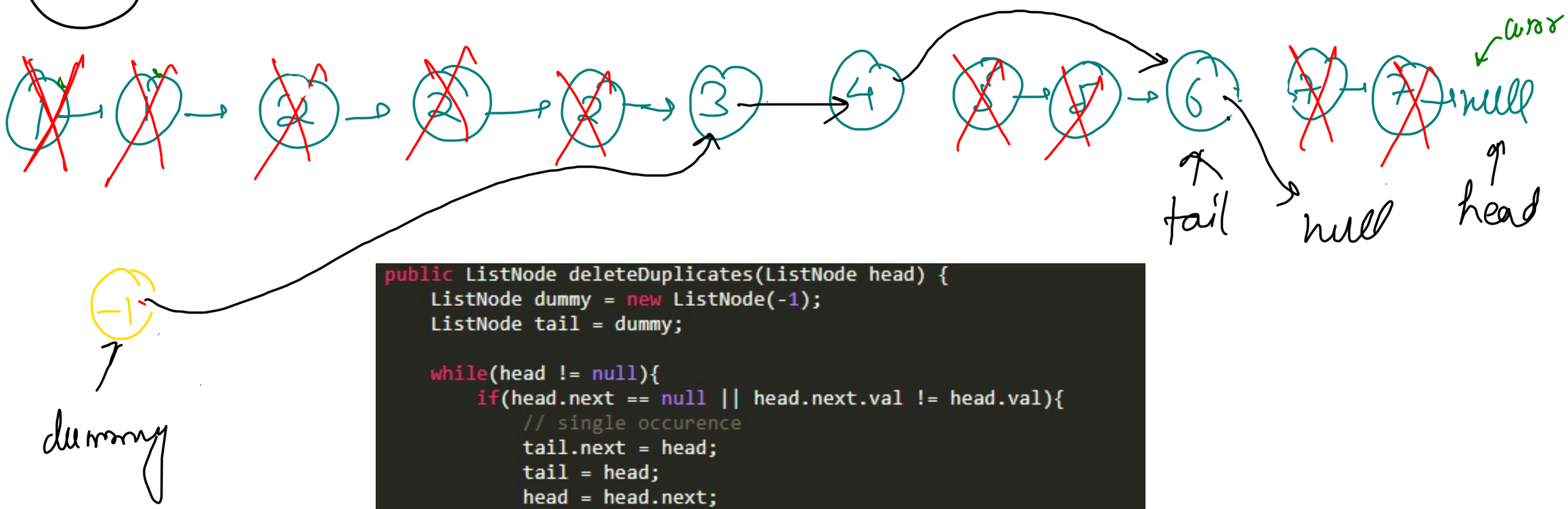
```
public ListNode deleteDuplicates(ListNode head) {
    ListNode dummy = new ListNode(-1);
    ListNode tail = dummy;

    while(head != null){
        if(tail == dummy || head.val != tail.val){
            tail.next = head;
            tail = head;
        }
        head = head.next;
    }

    tail.next = null;
    return dummy.next;
}
```

O(N) Time Complexity

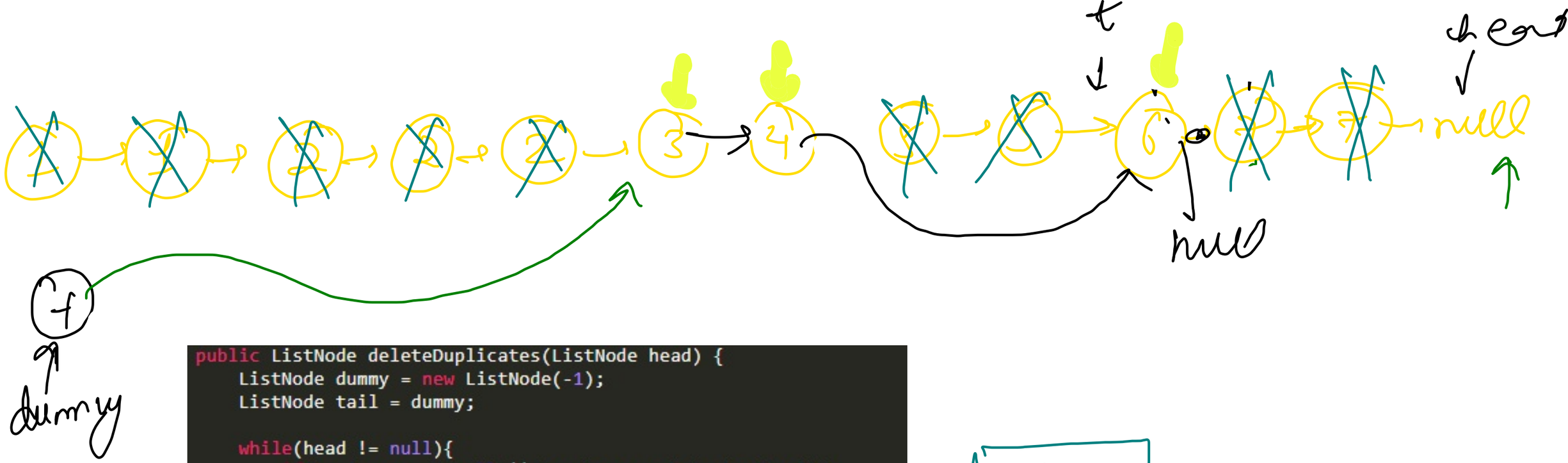



```java
public ListNode deleteDuplicates(ListNode head) {
    ListNode dummy = new ListNode(-1);
    ListNode tail = dummy;

    while(head != null){
        if(tail == dummy || head.val != tail.val){
            tail.next = head;
            tail = head;
        }
        head = head.next;
    }

    tail.next = null;
    return dummy.next;
}
```

82 Remove All Duplicates




```java
public ListNode deleteDuplicates(ListNode head) {
    ListNode dummy = new ListNode(-1);
    ListNode tail = dummy;

    while(head != null){
        if(head.next == null || head.next.val != head.val){
            // single occurence
            tail.next = head;
            tail = head;
            head = head.next;
        } else {
            // delete all occurences of head.val inclusing head
            ListNode curr = head;
            while(curr != null && curr.val == head.val){
                curr = curr.next;
            }
            head = curr;
        }
    }

    tail.next = null;
    return dummy.next;
}
```



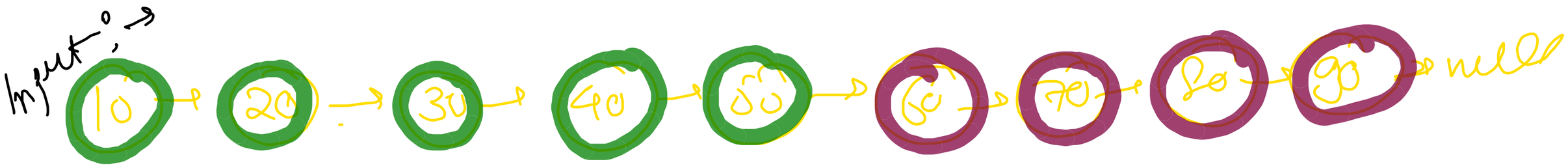

```java
public ListNode deleteDuplicates(ListNode head) {
    ListNode dummy = new ListNode(-1);
    ListNode tail = dummy;

    while(head != null){
        if(head.next == null || head.next.val != head.val){
            // single occurence
            tail.next = head;
            tail = head;
            head = head.next;
        } else {
            // delete all occurences of head.val inclusing head
            ListNode curr = head;
            while(curr != null && curr.val == head.val){
                curr = curr.next;
            }
            head = curr;
        }
    }

    tail.next = null;
    return dummy.next;
}
```

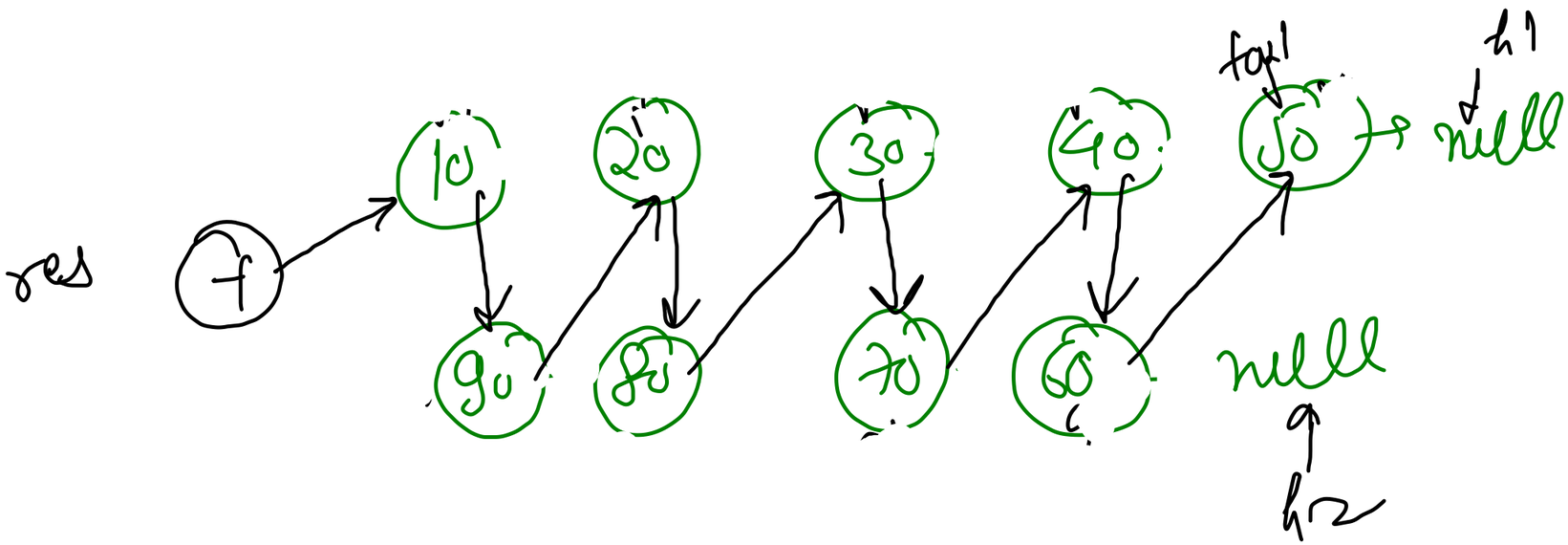
$\boxed{O(N)}$

Fold of LL { Reorder list (143) }

WHY?

Input :→



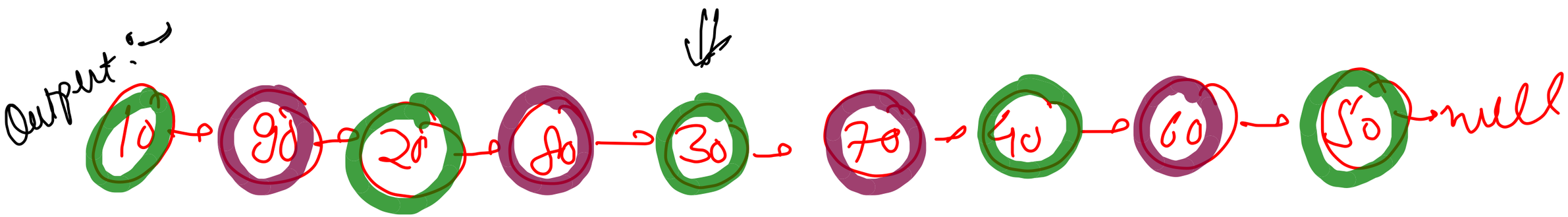


(1) Find middle → O(N)

(2) Second half - Reverse → O(N)

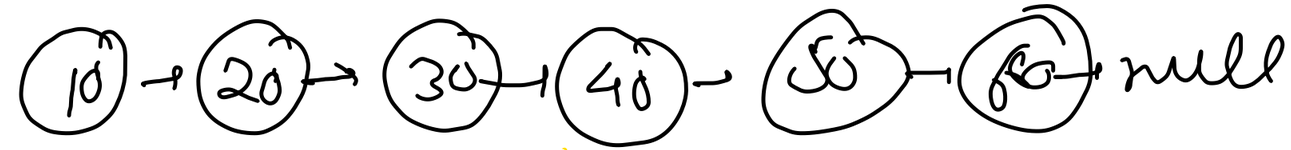
(3) Add Alternative Nodes → O(N)

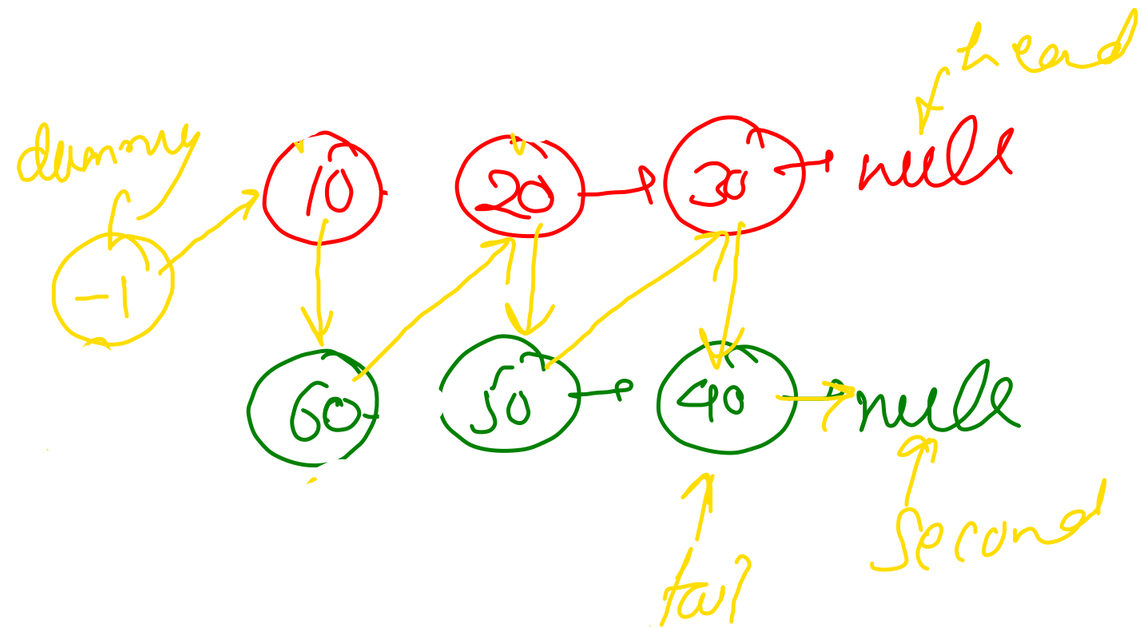
Output :→



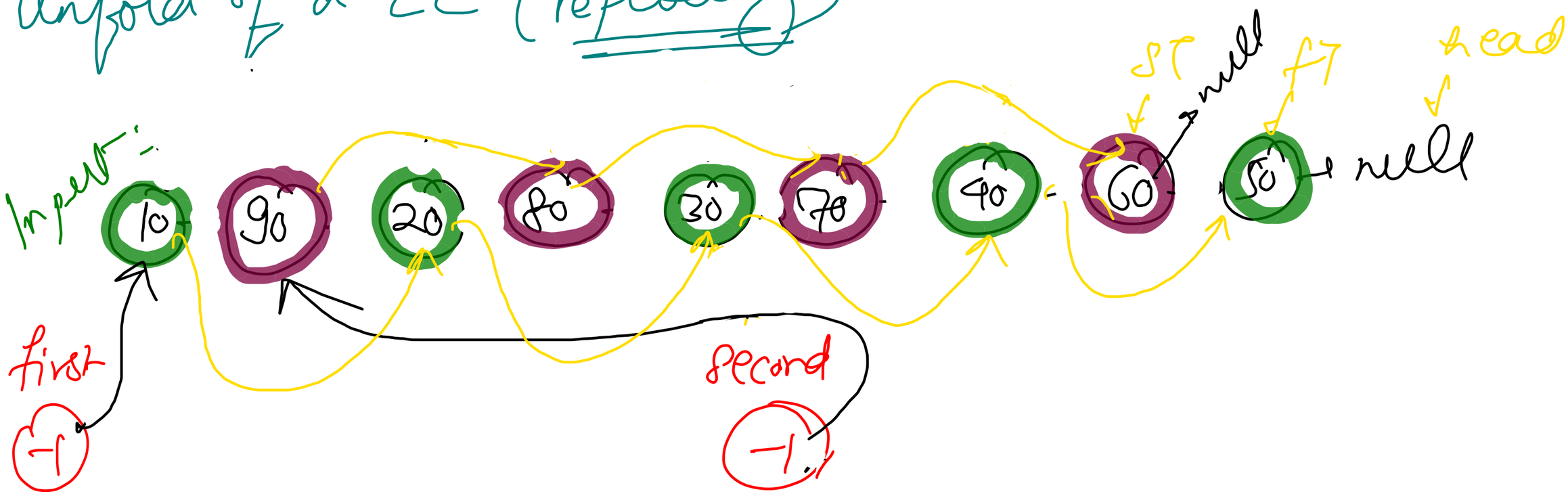
```java
public ListNode getMiddle(ListNode head){}
public ListNode reverse(ListNode head){}

public void reorderList(ListNode head) {
    ListNode mid = getMiddle(head);  → O(N)
    ListNode second = reverse(mid.next);  → O(N)
    mid.next = null;

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

    while(head != null || second != null){
        if(head != null){
            tail.next = head;
            tail = head;
            head = head.next;
        }
        if(second != null){
            tail.next = second;
            tail = second;
            second = second.next;
        }
    }

    tail.next = null;
    head = dummy.next;
}
```

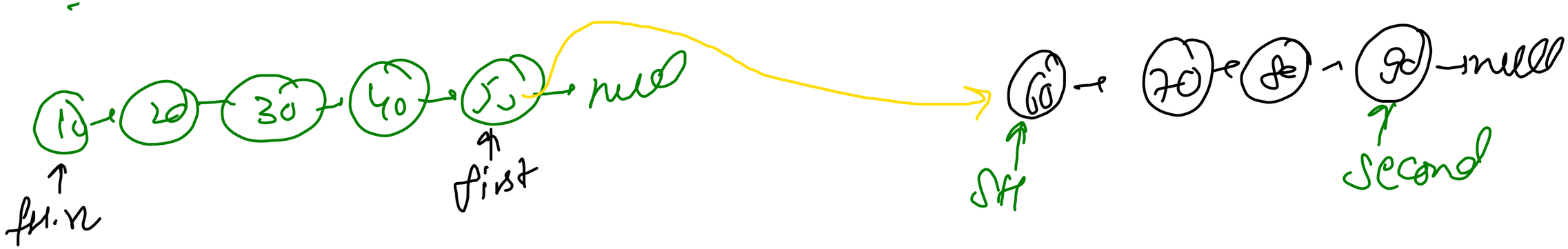
O(N)



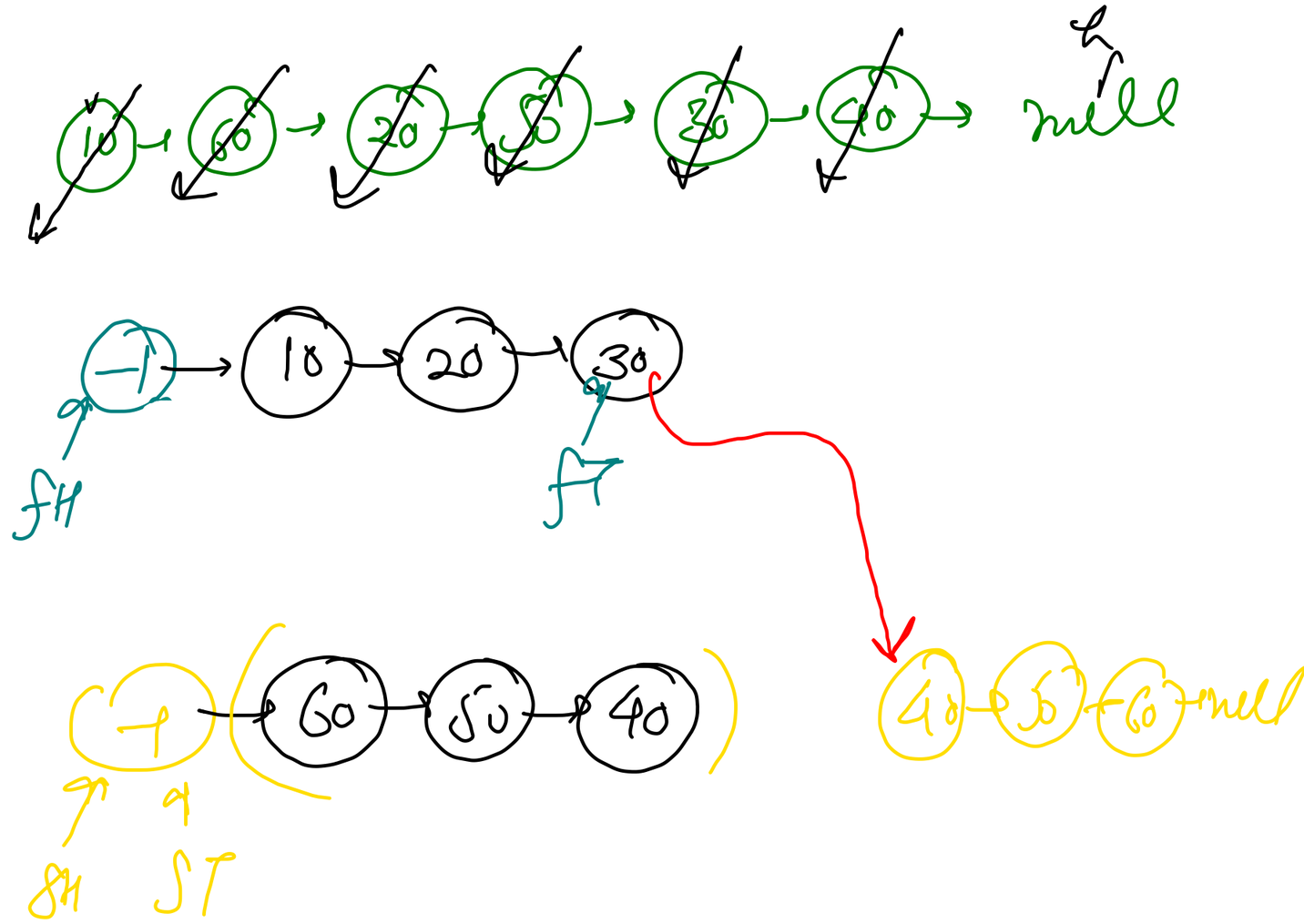


Unfold of a LL (Repeating)

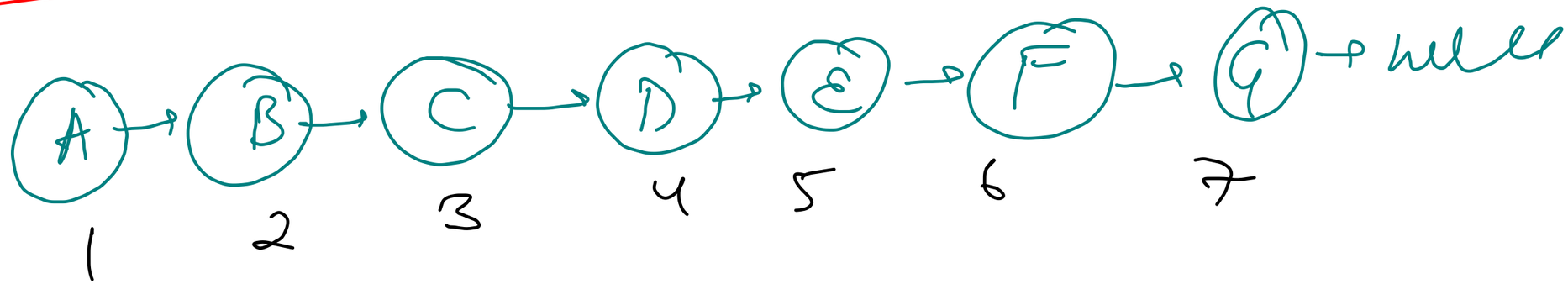


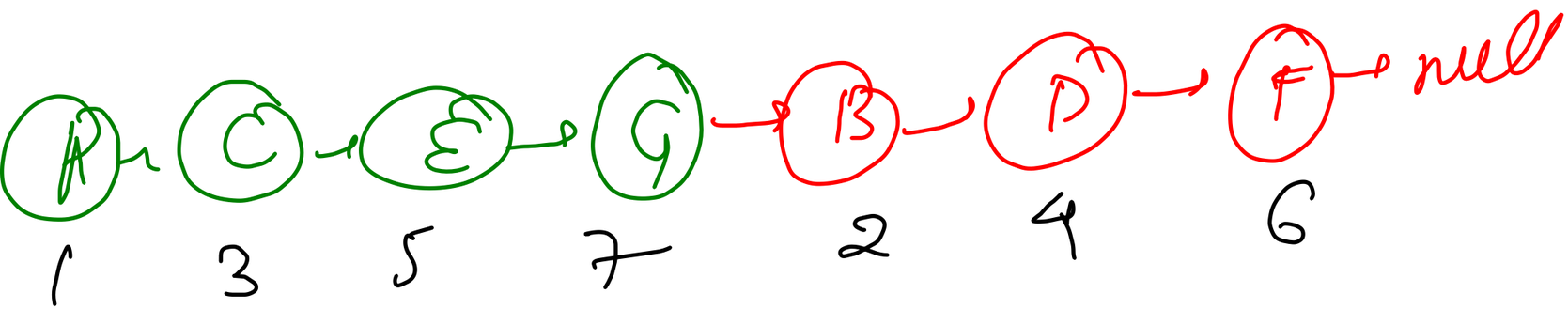


```java
public static ListNode reverse(ListNode head){...}

public static void unfold(ListNode head) {
    ListNode firstHead = new ListNode(-1);
    ListNode secondHead = new ListNode(-1);
    ListNode first = firstHead, second = secondHead;

    while(head != null){
        first.next = head;
        first = head;
        head = head.next;

        if(head != null){
            second.next = head;
            second = head;
            head = head.next;
        }
    }

    first.next = null;
    second.next = null;
        head.val = 1
    first.next = reverse(secondHead.next);
    ~~head = firstHead.next;~~
}
```



Odd Even LL (By Index) {Unfold}

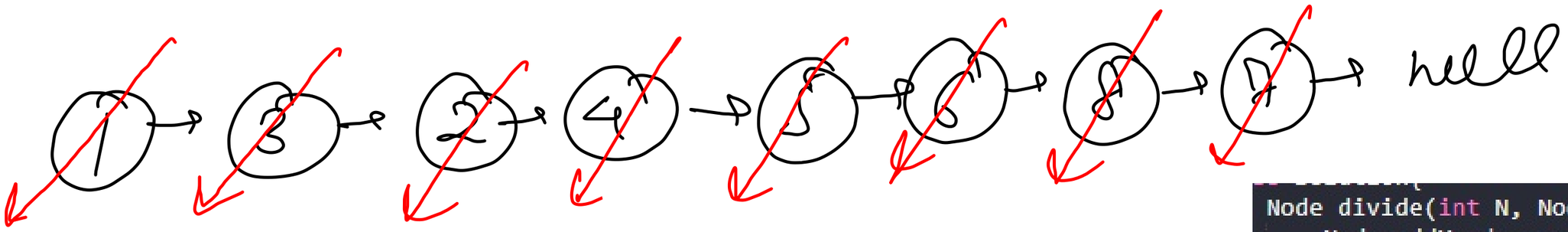


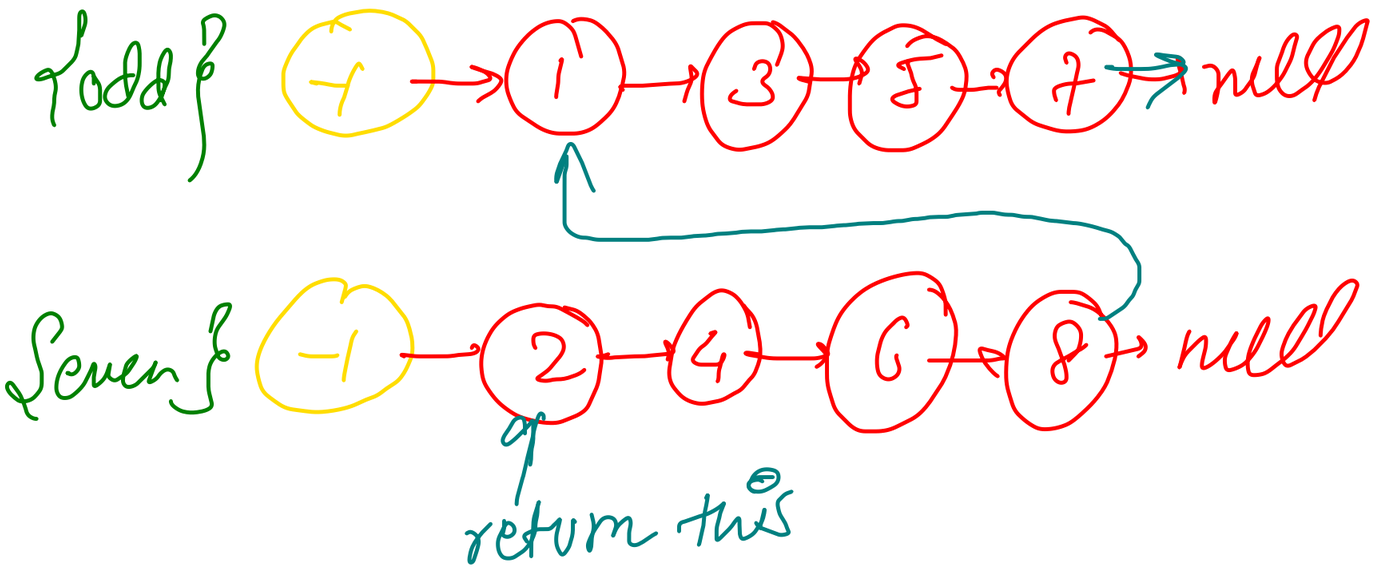



```java
public ListNode oddEvenList(ListNode head) {
    ListNode firstHead = new ListNode(-1);
    ListNode secondHead = new ListNode(-1);
    ListNode first = firstHead, second = secondHead;

    while(head != null){
        first.next = head;
        first = head;
        head = head.next;

        if(head != null){
            second.next = head;
            second = head;
            head = head.next;
        }
    }

    second.next = null;
    first.next = secondHead.next;
    return firstHead.next;
}
```

Odd Even LL {By value} $\boxed{\text{Sort 01}}$

Stable






```java
Node divide(int N, Node head){
    Node oddHead = new Node(-1);
    Node evenHead = new Node(-1);
    Node odd = oddHead, even = evenHead;

    while(head != null){
        if(head.data % 2 == 1){
            odd.next = head;
            odd = head;
        } else {
            even.next = head;
            even = head;
        }
        head = head.next;
    }

    odd.next = null;
    even.next = oddHead.next;
    return evenHead.next;
}
```

Lecture 8 { Thursday → Level 2 }

Pre-requisite → Hashmap

V. IMP. → Design LRU Cache 146

→ Design LFU Cache 460

→ Copy linked list with Random Ptr 138

- → With Extra Space
- → W/o Extra Space

Design a data structure that follows the constraints of a **Least Recently Used (LRU) cache**.

Implement the `LRUCache` class:

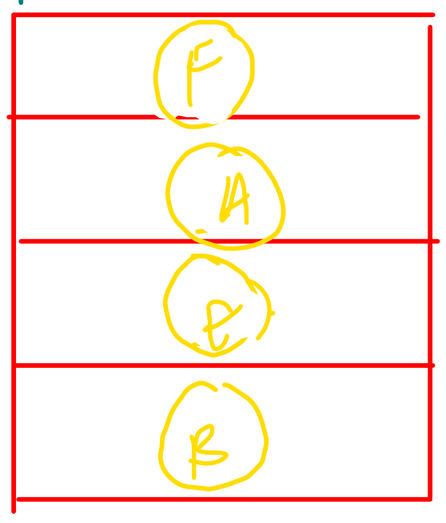
- `LRUCache(int capacity)` Initialize the LRU cache with **positive** size `capacity`.
- `int get(int key)` Return the value of the `key` if the key exists, otherwise return `-1`.
- `void put(int key, int value)` Update the value of the `key` if the `key` exists. Otherwise, add the `key-value` pair to the cache. If the number of keys exceeds the `capacity` from this operation, **evict** the least recently used key.

The functions `get` and `put` must each run in `O(1)` average time complexity.

LRU Cache

get → If key found → return value
→ Top
Else return -1

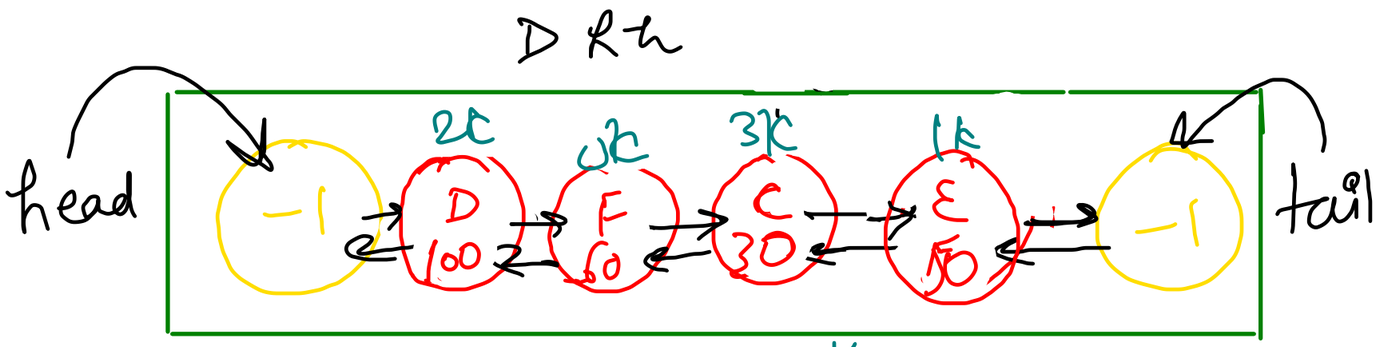
search



A, Hi
B, Hello
A, What's up?
C, Hi
D, Hello

search (B) (Hello)
search (E) (-1)
E, DSA
search (A) (-1)
A, Hi
B, Core
F, Hatden

put → If key found update
Delete → top insert
Insert at top
{ delete last if cap is full }



hashmap<Int, Node>

E → 1k
D → 2k
C → 3k
F → 5k

RL
O(1) + O(1)

O(1) (1) put (A, 10)

O(1) (2) put (B, 20)

O(1) (3) put (C, 30)

O(1) (4) put (D, 40)

(5) put (E, 50)

O(1) (6) get (A) (-1)

O(1) (7) get (C) (30)

O(1) (8) put (D, 50)

O(1) (9) put (F, 60)

(10) get (B) -1

(11) get (D) 50

(12) put (D, 100) 100

curr = tail.prev

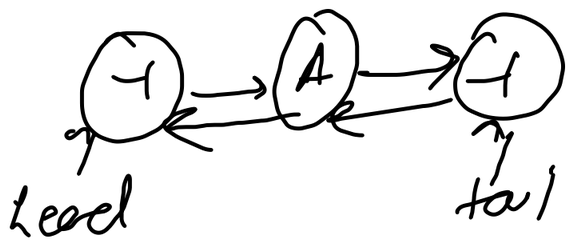
Remove

curr.prev.next = curr.next

curr.next.prev = curr.prev

Dlh

Remove At



curr.prev.next
= curr.next

curr.next.prev
= curr.prev

Add First

curr.prev = head
curr.next = head.next
curr.prev.next = curr
curr.next.prev = curr

```java
public static class Node{
    int key;
    int val;
    Node prev;
    Node next;
    Node(int key, int val){
        this.key = key;
        this.val = val;
    }
}
```

```java
int size = 0, capacity;
Node head, tail;
HashMap<Integer, Node> hm;

public LRUCache(int capacity) {
    this.capacity = capacity;
    head = new Node(-1, -1);
    tail = new Node(-1, -1);
    head.next = tail;
    tail.prev = head;
    size = 0;
    hm = new HashMap<>();
}
```

```java
public int get(int key) {
    if(hm.containsKey(key) == false)
        return -1;

    Node curr = hm.get(key);

    // Remove At
    curr.prev.next = curr.next;
    curr.next.prev = curr.prev;

    // Add First
    curr.prev = head;
    curr.next = head.next;
    curr.prev.next = curr;
    curr.next.prev = curr;

    return curr.val;
}
```

```java
public void put(int key, int value) {
    if(hm.containsKey(key) == false){
        // Insert
        Node curr = new Node(key, value);

        if(size == capacity){
            // Remove Last
            Node temp = tail.prev;
            temp.prev.next = temp.next;
            temp.next.prev = temp.prev;
            hm.remove(temp.key);

        } else size++;

        // Add First
        curr.prev = head;
        curr.next = head.next;
        curr.prev.next = curr;
        curr.next.prev = curr;
        hm.put(key, curr);
```

```java
    } else {
        // Update
        Node curr = hm.get(key);

        // Remove At
        curr.prev.next = curr.next;
        curr.next.prev = curr.prev;

        // Add First
        curr.prev = head;
        curr.next = head.next;
        curr.prev.next = curr;
        curr.next.prev = curr;

        curr.val = value;
    }
```

LRU Cache

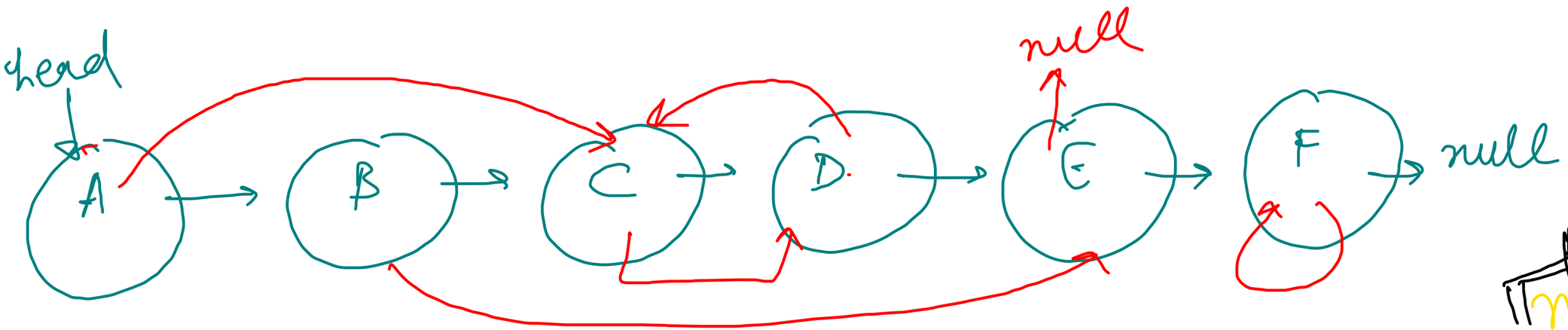
Copy linked list with Random Ptr

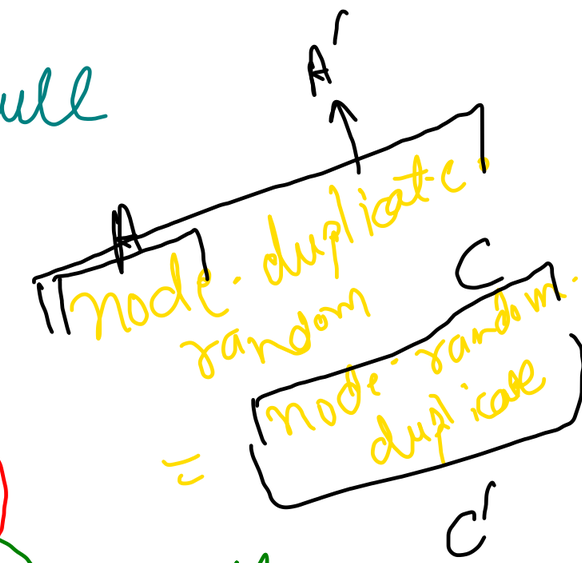
Deep copy

$O(N)$

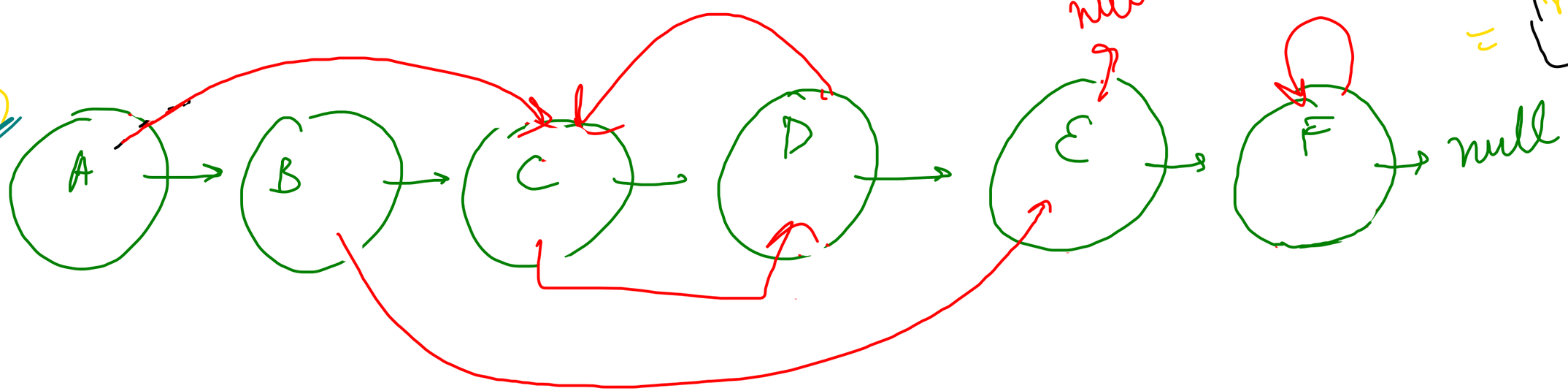
Hashmap<Node, Node>

original node → clone node





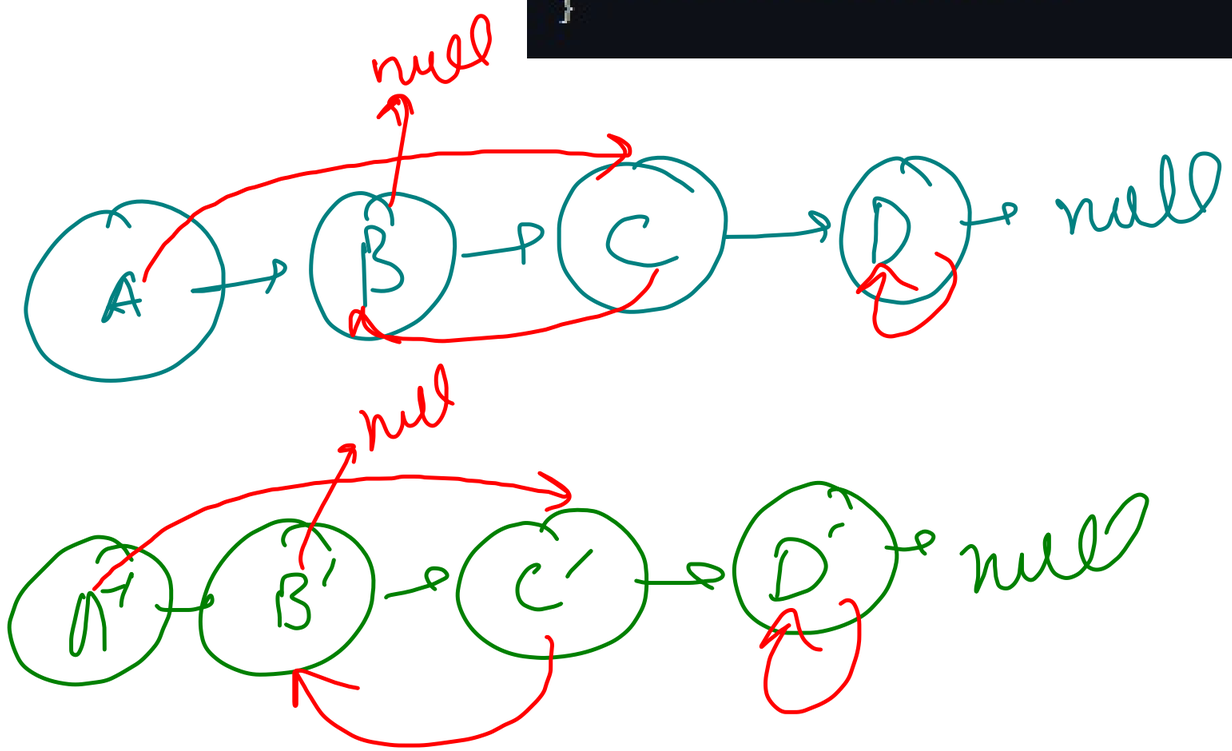
$O(N)$

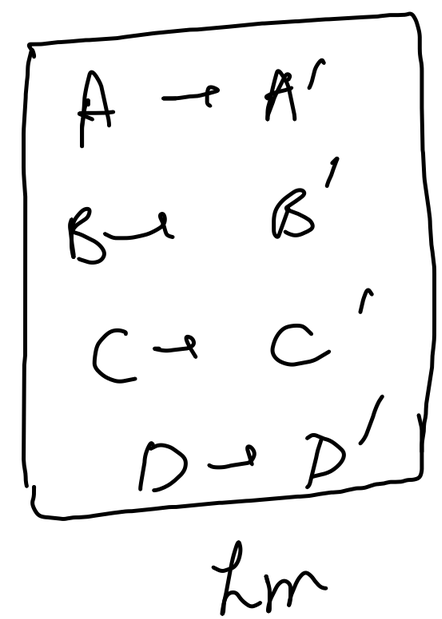


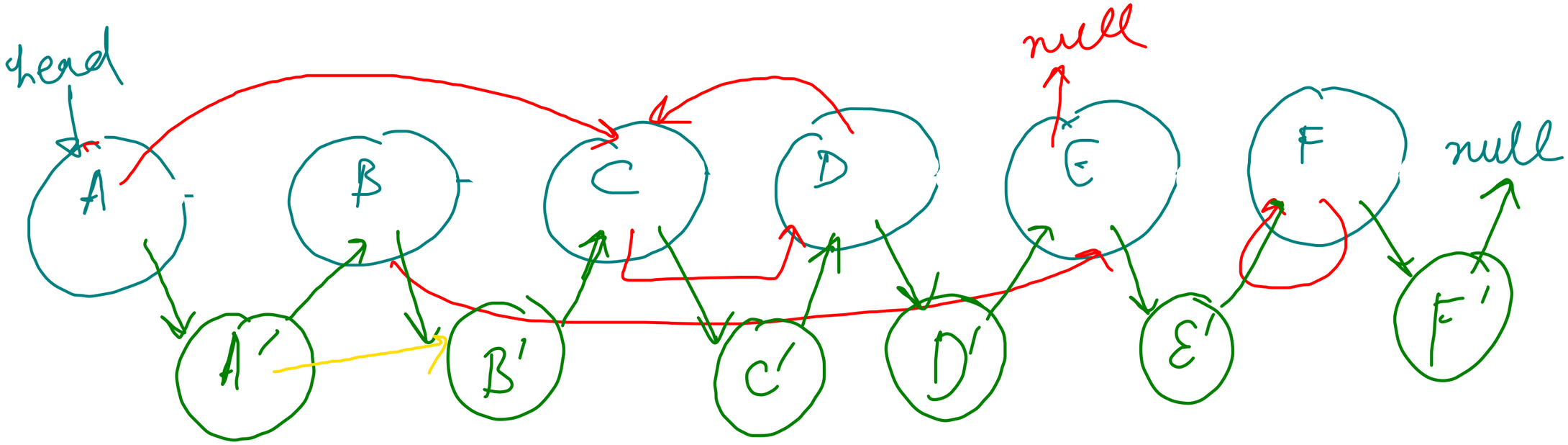
```java
HashMap<Node, Node> hm = new HashMap<>();
// Original Node -> Duplicate Node

Node copyHead = new Node(-1);
Node tail = copyHead;
```

```java
// Creation of Deep Copied Linked List
Node original = head;
while(original != null){
    Node duplicate = new Node(original.val);
    tail.next = duplicate;
    tail = duplicate;

    hm.put(original, duplicate);
    original = original.next;
}
```

```java
// Updating the Random Pointers
original = head;
while(original != null){
    Node randomNode = original.random;
    if(randomNode != null){
        randomNode = hm.get(randomNode);
    }

    hm.get(original).random = randomNode;
    original = original.next;
}
```







A.random = C

A'.random = C'

A'.next.random = C'.next

A.next.random = A.random.next

```java
Node original = head;

// Insert Duplicate Nodes in Between
while(original != null){
    Node duplicate = new Node(original.val);
    duplicate.next = original.next;
    original.next = duplicate;
    original = duplicate.next;
}
```

```java
original = head;
// Duplicate's Random Node Updation
while(original != null){
    Node randomNode = original.random;
    if(original.random != null)
        randomNode = randomNode.next;
    original.next.random = randomNode;
    original = original.next.next;
}
```

```java
original = head;
Node copyHead = head.next;

// Separating the original from duplicate
while(original != null){
    Node duplicate = original.next;
    original.next = original.next.next;

    if(duplicate.next != null)
    duplicate.next = duplicate.next.next;

    original = original.next;
}

return copyHead;
```

O(N) Time

O(1) extra space