

Unit-4

Linked List

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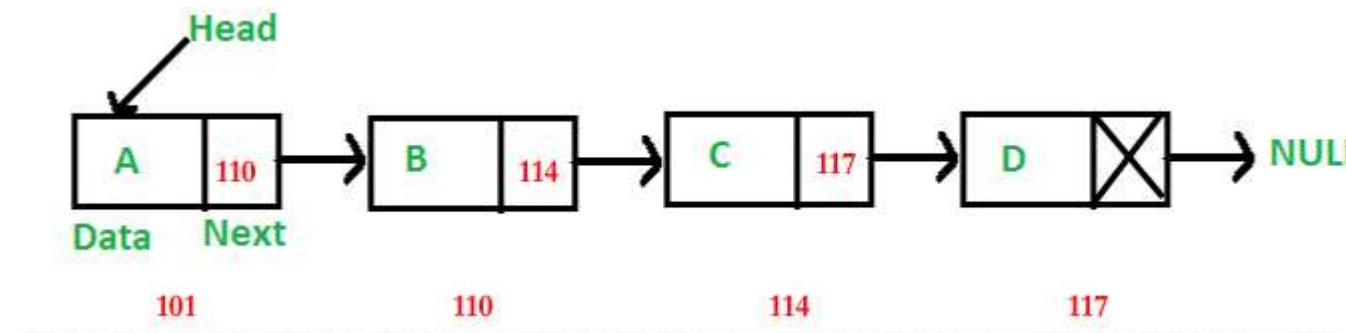
- Definition of Linked List
- Dynamic Memory Management,
- Representation of Linked List
- Operations on Linked List: Inserting, Removing, Searching, Sorting, Merging Nodes
- Double Linked List

Differences between Array based and linked based implementation

	Array	Linked List
Definition	Array is a collection of elements having same data type with common name	Linked list is an ordered collection of elements which are connected by links/pointers
Access	Elements can be accessed using index/subscript, random access	Sequential access
Memory structure	Elements are stored in contiguous memory locations	Elements are stored at available memory space
Insertion & Deletion	Insertion and deletion take more time in array	Insertion and deletion are fast and easy
Memory Allocation	Memory is allocated at compile time i.e static memory allocation	Memory is allocated at run time i.e dynamic memory allocation
Types	1D, 2D, multi-dimensional	SLL, DLL, circular linked list
Dependency	Each element is independent	Each node is dependent on each other as address part contains address of next node in the list

Introduction

- Like arrays, Linked List is a linear data structure.
- Unlike arrays, linked list elements are not stored at a contiguous location;
- the elements are linked using pointers



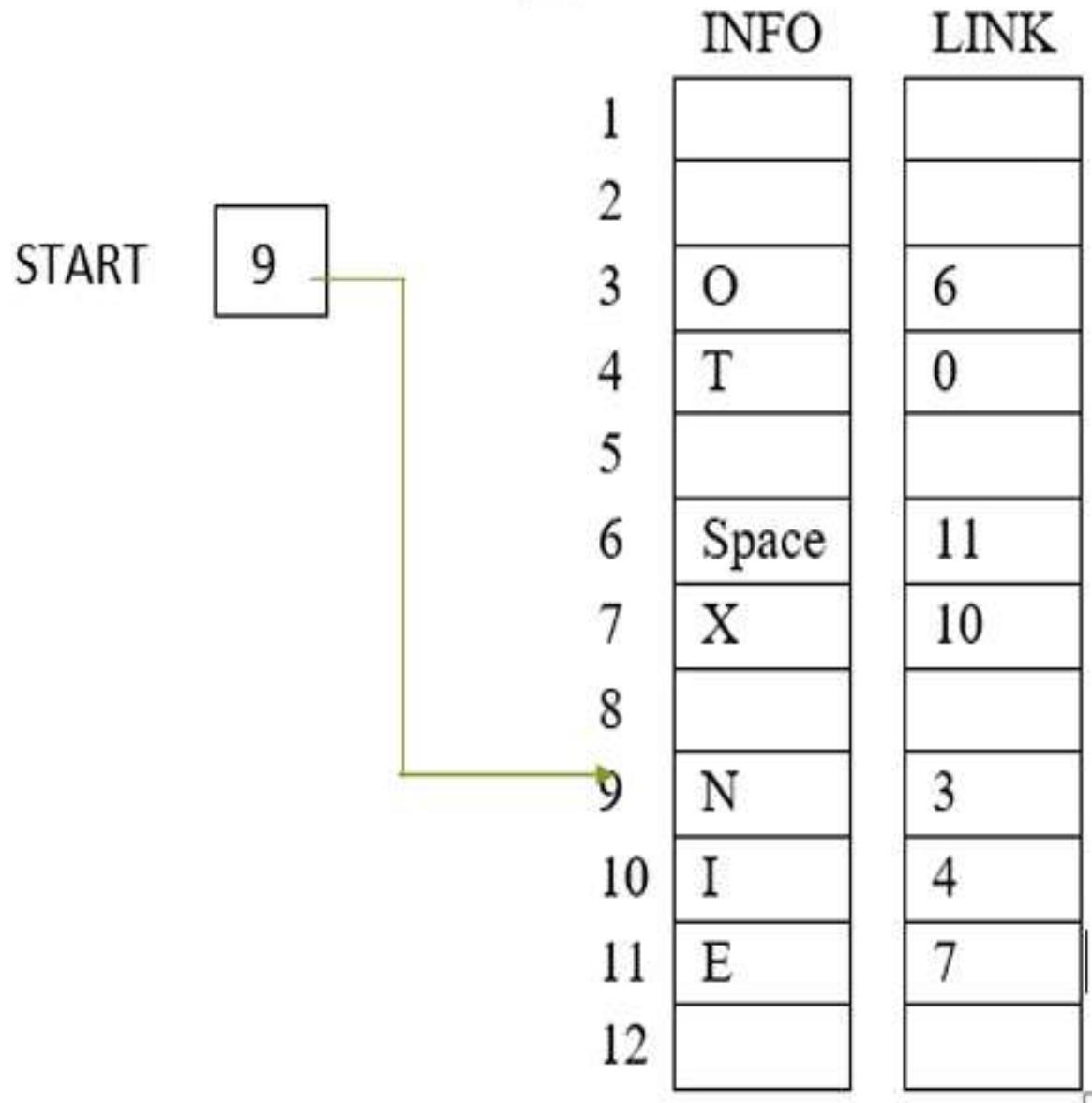
Why Linked List?

- Arrays can be used to store linear data of similar types, but arrays have the following limitations.
 - 1) The size of the arrays is fixed: So we must know the upper limit on the number of elements in advance. Also, generally, the allocated memory is equal to the upper limit irrespective of the usage.
 - 2) Inserting a new element in an array of elements is expensive because the room has to be created for the new elements and to create room existing elements have to be shifted in a system,
if we maintain a sorted list of IDs in an array id[]. id[] = [1000, 1010, 1050, 2000, 2040].
if we want to insert a new ID 1005, then to maintain the sorted order, we have to move all the elements after 1000 (excluding 1000).
Deletion is also expensive with arrays until unless some special techniques are used. For example, to delete 1010 in id[], everything after 1010 has to be moved

Representation:

- A linked list is represented by a pointer to the first node of the linked list. The first node is called the head.
- If the linked list is empty, then the value of the head is NULL.
- Each node in a list consists of at least two parts: 1) data 2) Pointer (Or Reference) to the next node
- In C, we can represent a node using structures. Below is an example of a linked list node with integer data.

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



Let LIST be a linked list. Then LIST will be maintained in memory specified as follows.

First of all, LIST requires two linear arrays we will call them here INFO and LINK- such that INFO[K] and LINK[K] contain, respectively, the information part and the nextpointer field of a node LIST.

LIST also requires a variable name- such as START.

START contains the location of the beginning of the list, and a nextpointer sentinel -denoted by NULL- which indicate the end of the list. Since the subscripts of the array INFO and LINK are usually positive, we will choose NULL=0

START pointing to the first element of the linked list in the memory

- Above picture is of linked list in memory where each node of the list contains a single character. We can obtain the actual list of characters as follows.

START= 9, so INFO[9]=N is the first character.

LINK[9]=3, so INFO[3]=O is the second character.

LINK[3]=6, so INFO[6]= (Blank) is the third character.

LINK[6]=11, so INFO[11]=E is the fourth character.

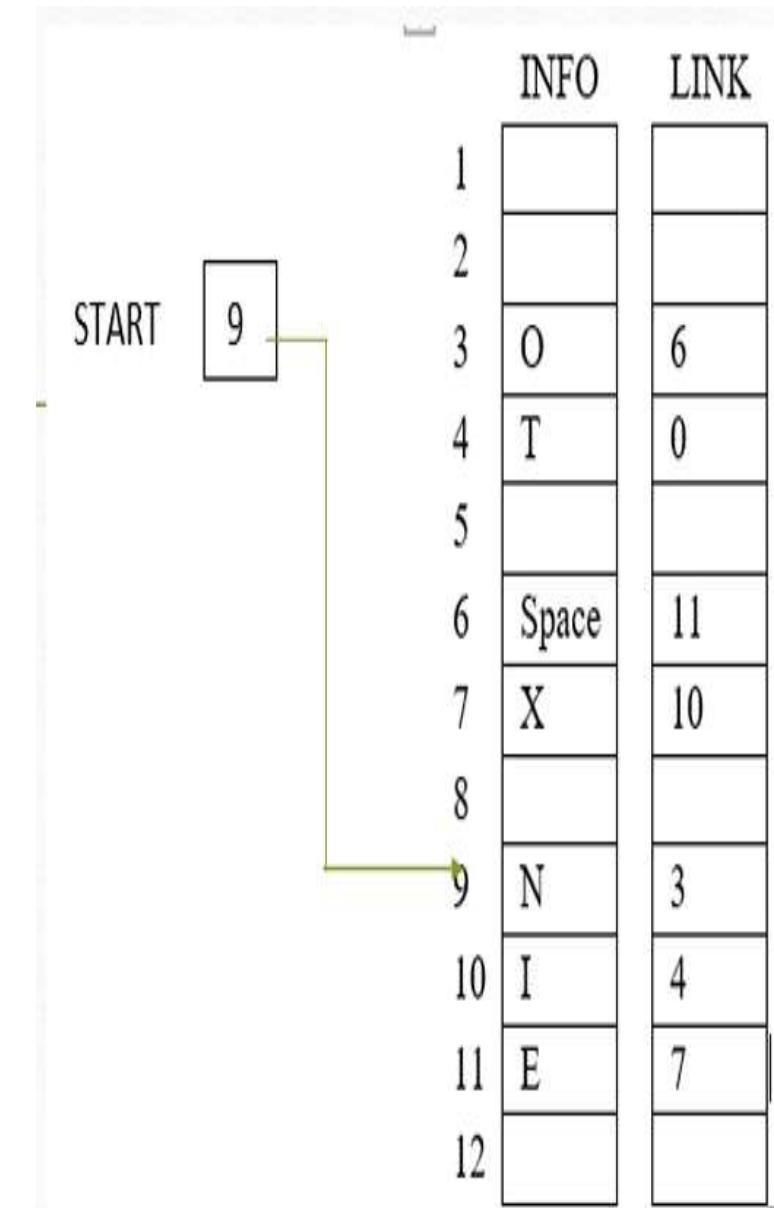
LINK[11]=7, so INFO[7]=X is the fifth character.

LINK[7]=10, so INFO[10]=I is the sixth character.

LINK[10]=4, so INFO[4]=T is the seventh character.

LINK[4]=0, the NULL value, so the List has ended.

In other words, NO EXIT is the character string

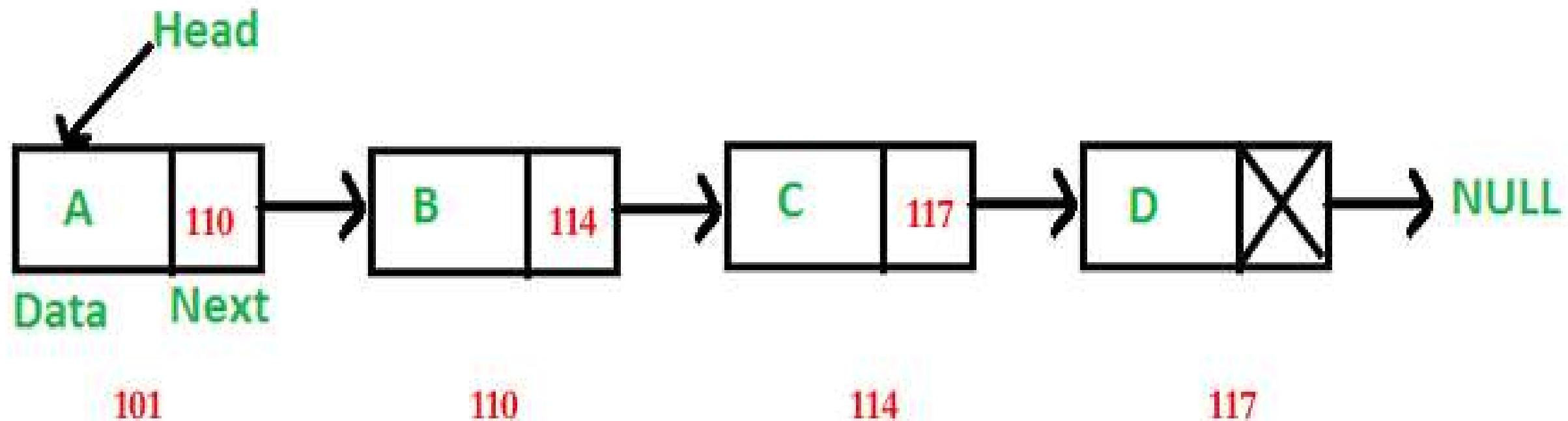


Types of Linked List

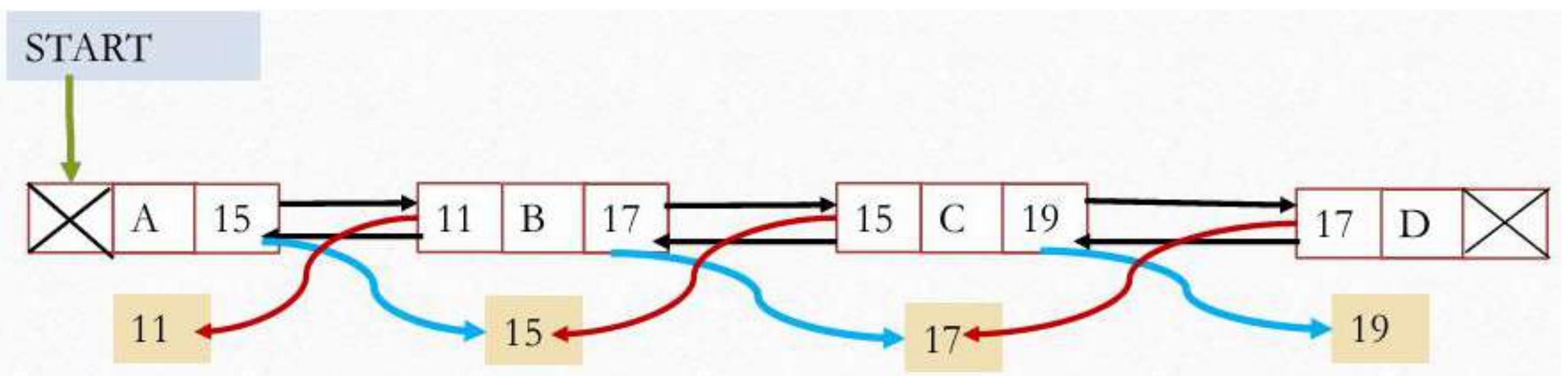
Following are the various types of linked list.

- Simple Linked List – Item navigation is forward only.
- Doubly Linked List – Items can be navigated forward and backward.
- Circular Linked List – Last item contains link of the first element as next and the first element has a link to the last element as previous

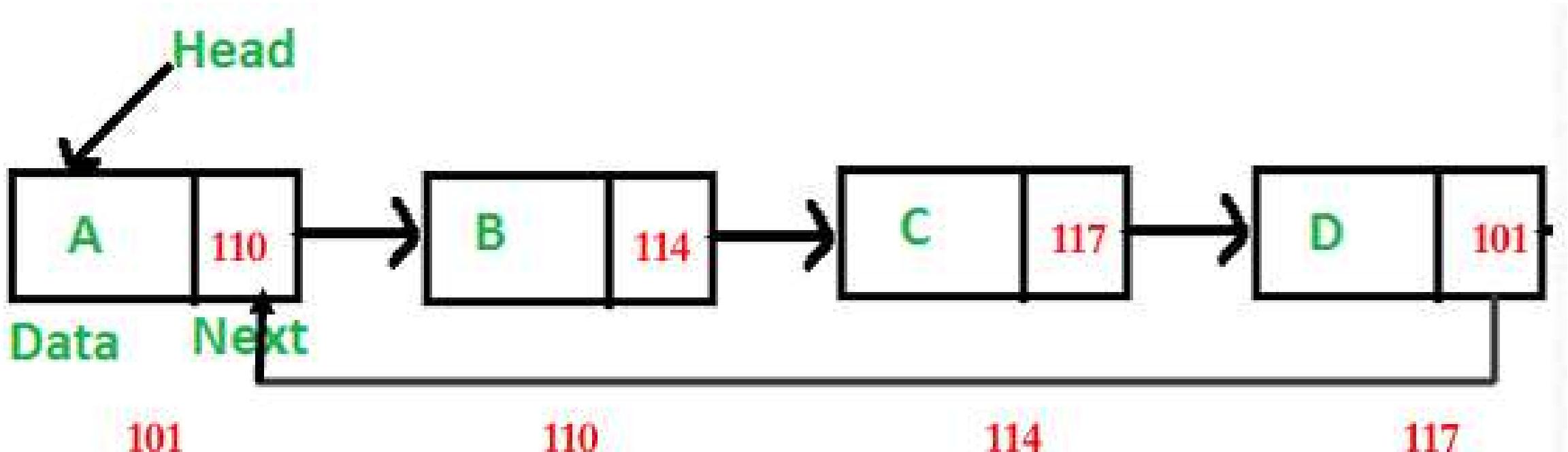
Simple Linked List



Doubly Linked List

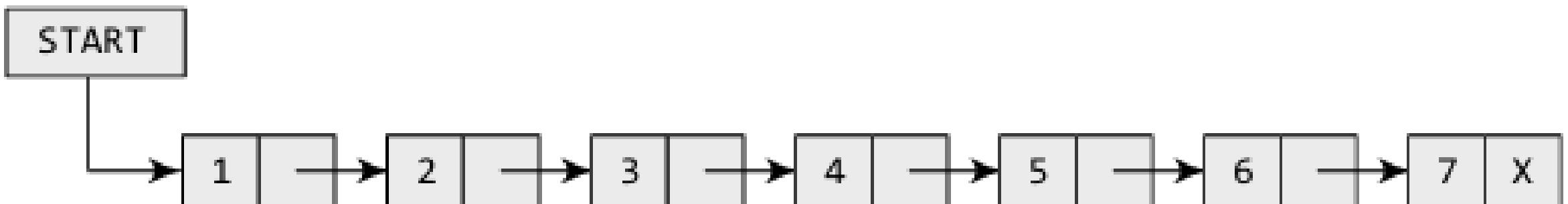


Circular Linked List



Singly Linked List

- A singly linked list is the simplest type of linked list in which every node contains some data and a pointer to the next node of the same data type.
- By saying that the node contains a pointer to the next node, we mean that the node stores the address of the next node in sequence. A singly linked list allows traversal of data only in one way



Traversing a Linked List

Step 1: [INITIALIZE] SET PTR = START

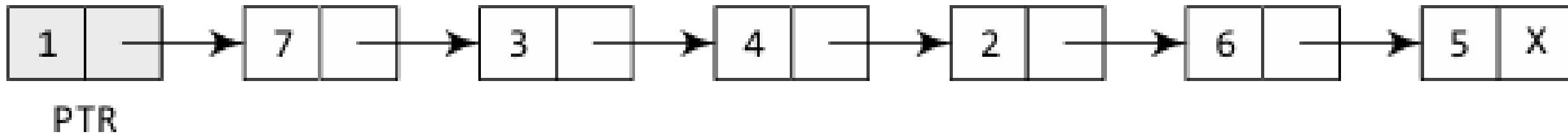
Step 2: Repeat Steps 3 and 4 while PTR != NULL

Step 3: Apply Process to PTR → DATA

Step 4: SET PTR = PTR → NEXT

 [END OF LOOP]

Step 5: EXIT



To print the number of nodes in a linked list

Step 1: [INITIALIZE] SET COUNT = 0

Step 2: [INITIALIZE] SET PTR = START

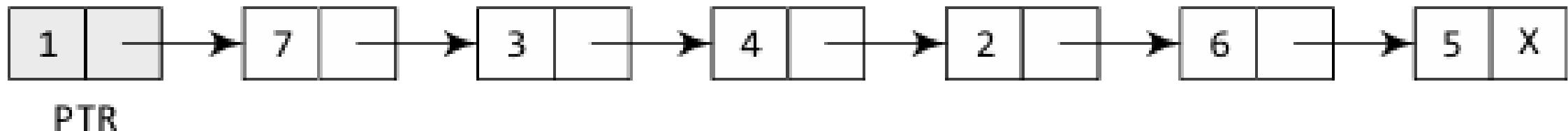
Step 3: Repeat Steps 4 and 5 while PTR != NULL

Step 4: SET COUNT = COUNT + 1

Step 5: SET PTR = PTR -> NEXT
 [END OF LOOP]

Step 6: Write COUNT

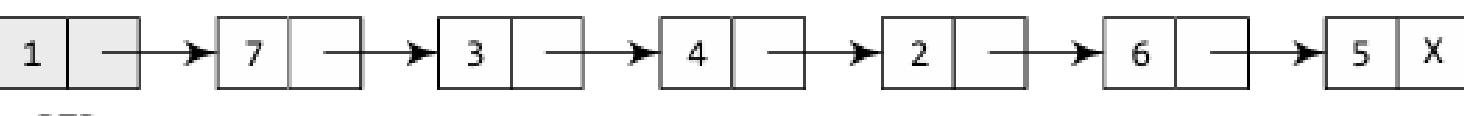
Step 7: EXIT



Searching for a value in a Linked List

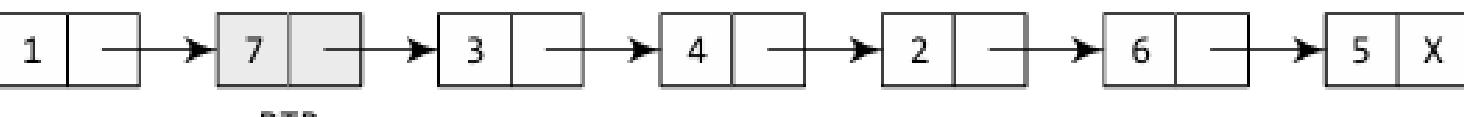
```
Step 1: [INITIALIZE] SET PTR = START  
Step 2: Repeat Step 3 while PTR != NULL  
Step 3:     IF VAL = PTR->DATA  
             SET POS = PTR  
             Go To Step 5  
     ELSE  
             SET PTR = PTR->NEXT  
     [END OF IF]  
 [END OF LOOP]  
Step 4: SET POS = NULL  
Step 5: EXIT
```

If we have VAL = 4, then the flow of the algorithm can be explained as shown in the figure.



PTR

Here PTR → DATA = 1. Since PTR → DATA != 4, we move to the next node.



PTR

Here PTR → DATA = 7. Since PTR → DATA != 4, we move to the next node.



PTR

Here PTR → DATA = 3. Since PTR → DATA != 4, we move to the next node.



PTR

Here PTR → DATA = 4. Since PTR → DATA = 4, POS = PTR. POS now stores the address of the node that contains VAL.

Inserting a new node in a Linked List

Case 1: The new node is inserted at the beginning.

Case 2: The new node is inserted at the end.

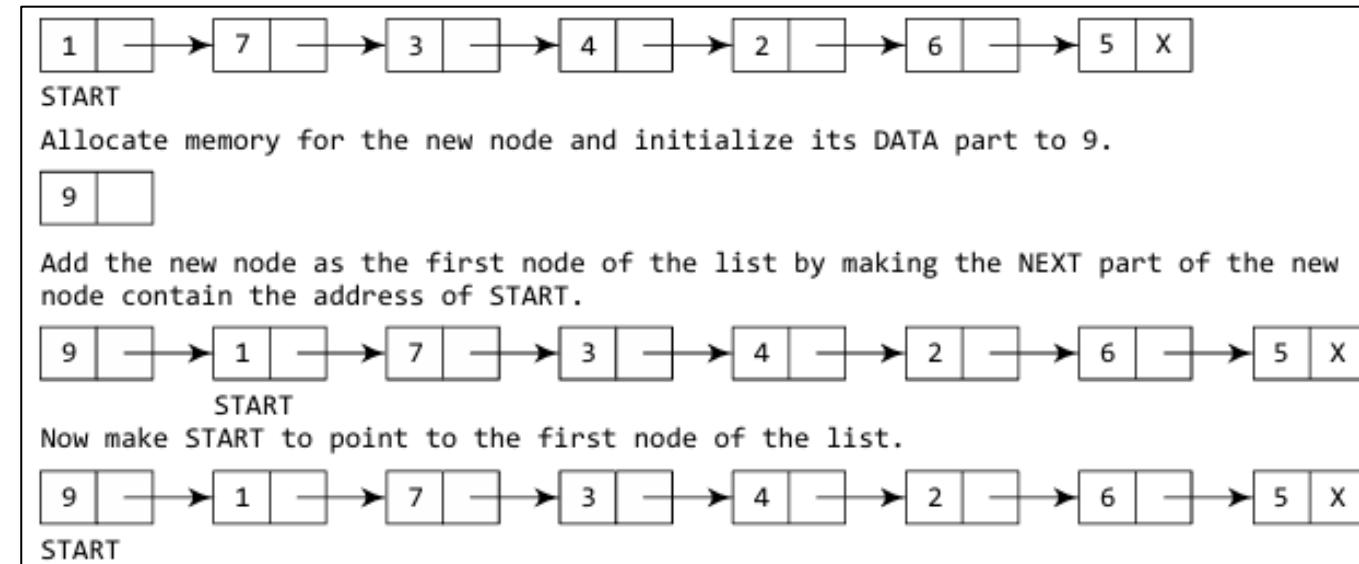
Case 3: The new node is inserted after a given node.

Case 4: The new node is inserted before a given node

Inserting a Node at the Beginning of a Linked List

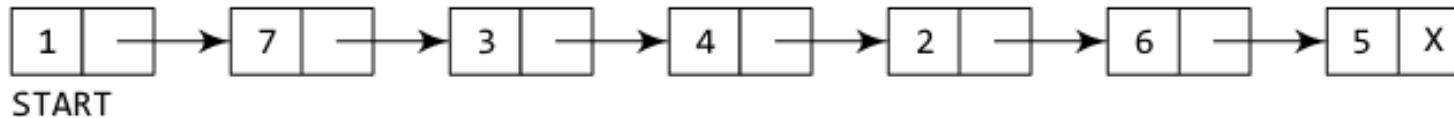
```
Step 1: IF AVAIL = NULL  
        Write OVERFLOW  
        Go to Step 7  
    [END OF IF]
```

```
Step 2: SET NEW_NODE = AVAIL  
Step 3: SET AVAIL = AVAIL -> NEXT  
Step 4: SET NEW_NODE -> DATA = VAL  
Step 5: SET NEW_NODE -> NEXT = START  
Step 6: SET START = NEW_NODE  
Step 7: EXIT
```

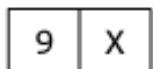


Inserting a Node at the End of a Linked List

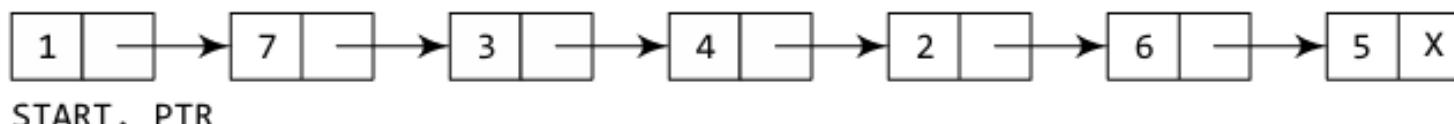
- Insert node 9 at end



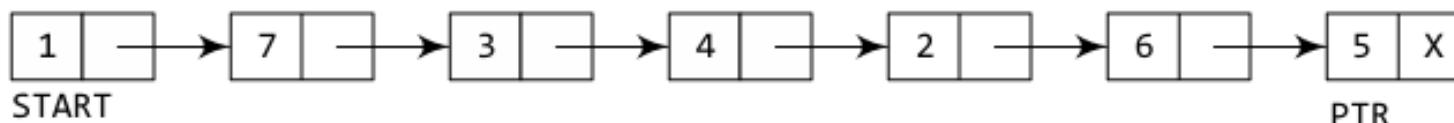
Allocate memory for the new node and initialize its DATA part to 9 and NEXT part to NULL.



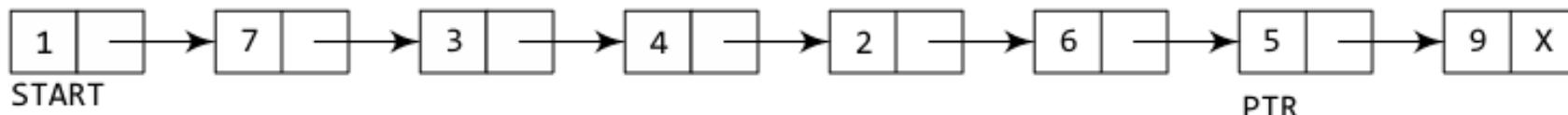
Take a pointer variable PTR which points to START.



Move PTR so that it points to the last node of the list.



Add the new node after the node pointed by PTR. This is done by storing the address of the new node in the NEXT part of PTR.



```
Step 1: IF AVAIL = NULL  
        Write OVERFLOW  
        Go to Step 10  
    [END OF IF]  
Step 2: SET NEW_NODE = AVAIL  
Step 3: SET AVAIL = AVAIL -> NEXT  
Step 4: SET NEW_NODE -> DATA = VAL  
Step 5: SET NEW_NODE -> NEXT = NULL  
Step 6: SET PTR = START  
Step 7: Repeat Step 8 while PTR -> NEXT != NULL  
Step 8:     SET PTR = PTR -> NEXT  
    [END OF LOOP]  
Step 9: SET PTR -> NEXT = NEW_NODE  
Step 10: EXIT
```

Insert a new node after a node that has value NUM

Step 1: IF AVAIL = NULL
 Write OVERFLOW
 Go to Step 12

[END OF IF]

Step 2: SET NEW_NODE = AVAIL

Step 3: SET AVAIL = AVAIL->NEXT

Step 4: SET NEW_NODE->DATA = VAL

Step 5: SET PTR = START

Step 6: SET PREPTR = PTR

Step 7: Repeat Steps 8 and 9 while PREPTR->DATA
 != NUM

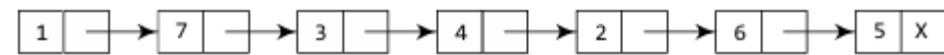
Step 8: SET PREPTR = PTR

Step 9: SET PTR = PTR->NEXT
 [END OF LOOP]

Step 10: PREPTR->NEXT = NEW_NODE

Step 11: SET NEW_NODE->NEXT = PTR

Step 12: EXIT



START
Allocate memory for the new node and initialize its DATA part to 9.



Take two pointer variables PTR and PREPTR and initialize them with START so that START, PTR, and PREPTR point to the first node of the list.



START
PTR
PREPTR

Move PTR and PREPTR until the DATA part of PREPTR = value of the node after which insertion has to be done. PREPTR will always point to the node just before PTR.

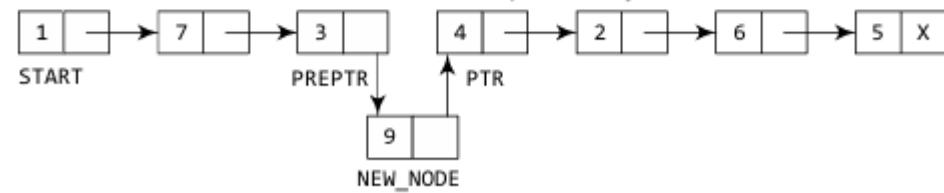


START PREPTR PTR



START PREPTR PTR

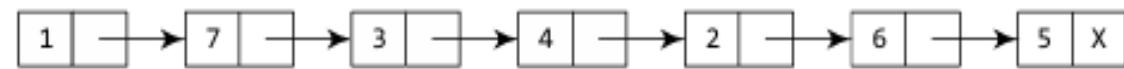
Add the new node in between the nodes pointed by PREPTR and PTR.



START

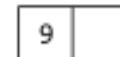
Inserting a Node Before a Given Node in a Linked List

```
Step 1: IF AVAIL = NULL  
        Write OVERFLOW  
        Go to Step 12  
    [END OF IF]  
Step 2: SET NEW_NODE = AVAIL  
Step 3: SET AVAIL = AVAIL -> NEXT  
Step 4: SET NEW_NODE -> DATA = VAL  
Step 5: SET PTR = START  
Step 6: SET PREPTR = PTR  
Step 7: Repeat Steps 8 and 9 while PTR -> DATA != NUM  
Step 8:     SET PREPTR = PTR  
Step 9:     SET PTR = PTR -> NEXT  
    [END OF LOOP]  
Step 10: PREPTR -> NEXT = NEW_NODE  
Step 11: SET NEW_NODE -> NEXT = PTR  
Step 12: EXIT
```



START

Allocate memory for the new node and initialize its DATA part to 9.



Initialize PREPTR and PTR to the START node.



START

PTR

PREPTR

Move PTR and PREPTR until the DATA part of PTR = value of the node before which insertion has to be done. PREPTR will always point to the node just before PTR.

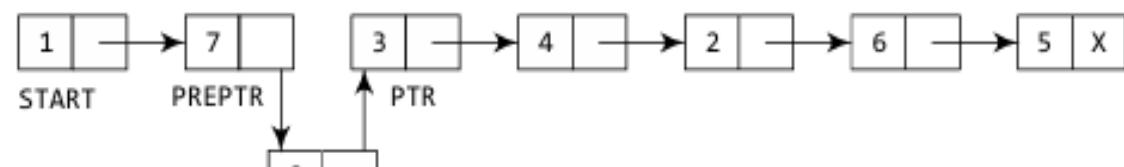


START

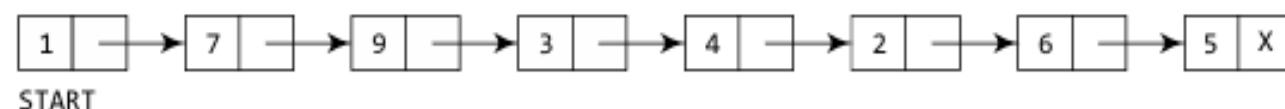
PREPTR

PTR

Insert the new node in between the nodes pointed by PREPTR and PTR.



NEW_NODE



START

Deleting a node from a Linked List

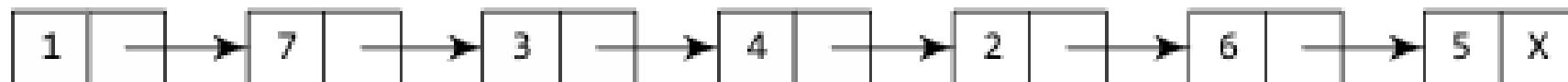
Case 1: The first node is deleted.

Case 2: The last node is deleted.

Case 3: The node after a given node is deleted.

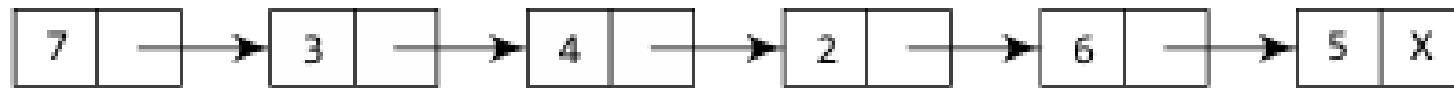
Deleting the first node of a linked list

```
Step 1: IF START = NULL  
        Write UNDERFLOW  
        Go to Step 5  
    [END OF IF]  
Step 2: SET PTR = START  
Step 3: SET START = START -> NEXT  
Step 4: FREE PTR  
Step 5: EXIT
```



START

Make START to point to the next node in sequence.



START

Deleting the Last Node from a Linked List

```
Step 1: IF START = NULL  
        Write UNDERFLOW  
        Go to Step 8  
    [END OF IF]  
Step 2: SET PTR = START  
Step 3: Repeat Steps 4 and 5 while PTR -> NEXT != NULL  
Step 4:     SET PREPTR = PTR  
Step 5:     SET PTR = PTR -> NEXT  
    [END OF LOOP]  
Step 6: SET PREPTR -> NEXT = NULL  
Step 7: FREE PTR  
Step 8: EXIT
```



START

Take pointer variables PTR and PREPTR which initially point to START.



START

PREPTR

PTR

Move PTR and PREPTR such that NEXT part of PTR = NULL. PREPTR always points to the node just before the node pointed by PTR.

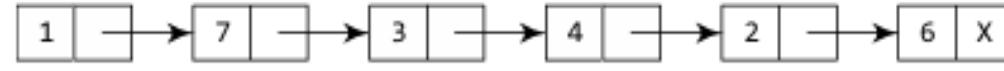


START

PREPTR

PTR

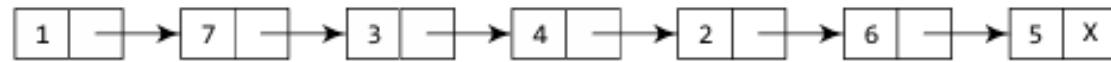
Set the NEXT part of PREPTR node to NULL.



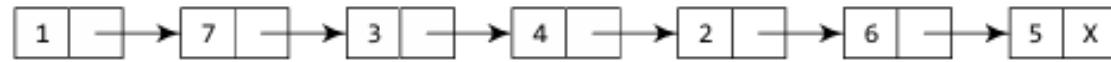
START

Deleting the Node After a Given Node in a Linked List

```
Step 1: IF START = NULL  
        Write UNDERFLOW  
        Go to Step 10  
    [END OF IF]  
Step 2: SET PTR = START  
Step 3: SET PREPTR = PTR  
Step 4: Repeat Steps 5 and 6 while PREPTR->DATA != NUM  
Step 5:     SET PREPTR = PTR  
Step 6:     SET PTR = PTR->NEXT  
    [END OF LOOP]  
Step 7: SET TEMP = PTR  
Step 8: SET PREPTR->NEXT = PTR->NEXT  
Step 9: FREE TEMP  
Step 10: EXIT
```



START
Take pointer variables PTR and PREPTR which initially point to START.



PREPTR
PTR

Move PREPTR and PTR such that PREPTR points to the node containing VAL and PTR points to the succeeding node.



START PREPTR PTR



START PREPTR PTR

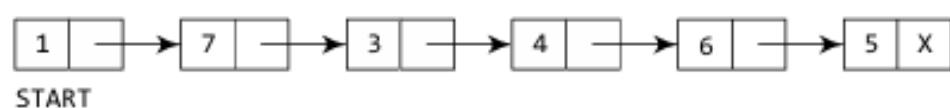


START PREPTR PTR

Set the NEXT part of PREPTR to the NEXT part of PTR.



START PREPTR PTR



START

Sort LinkedList in ascending order

Step 1: IF START = NULL OR START->NEXT = NULL

 Write "List is too short to sort"

 Go to Step 9

[END OF IF]

Step 2: SET PTR1 = START

Step 3: Repeat Steps 4 to 7 while PTR1 ≠ NULL

Step 4: SET PTR2 = PTR1->NEXT

Step 5: Repeat Steps 6 and 7 while PTR2 ≠ NULL

Step 6: IF PTR1->DATA > PTR2->DATA

 SET TEMP = PTR1->DATA

 SET PTR1->DATA = PTR2->DATA

 SET PTR2->DATA = TEMP

[END OF IF]

Step 7: SET PTR2 = PTR2->NEXT

[END OF INNER LOOP]

Step 8: SET PTR1 = PTR1->NEXT

[END OF OUTER LOOP]

Step 9: EXIT

Merging the node

Step 1: IF LIST1 = NULL

 SET MERGED_LIST = LIST2

 Go to Step 9

[END OF IF]

Step 2: IF LIST2 = NULL

 SET MERGED_LIST = LIST1

 Go to Step 9

[END OF IF]

Step 3: Initialize pointers:

 SET PTR1 = LIST1

 SET PTR2 = LIST2

 SET MERGED_LIST = NULL

 SET LAST = NULL

Step 4: Repeat Steps 5–7 while PTR1 ≠ NULL AND PTR2 ≠ NULL

Step 5: IF PTR1->DATA ≤ PTR2->DATA

 SET TEMP = PTR1

 SET PTR1 = PTR1->NEXT

ELSE

 SET TEMP = PTR2

 SET PTR2 = PTR2->NEXT

[END OF IF]

Step 6: IF MERGED_LIST = NULL

 SET MERGED_LIST = TEMP

 SET LAST = TEMP

ELSE

 SET LAST->NEXT = TEMP

 SET LAST = TEMP

[END OF IF]

Step 7: [END OF LOOP]

Step 8: IF PTR1 ≠ NULL

 SET LAST->NEXT = PTR1

 ELSE IF PTR2 ≠ NULL

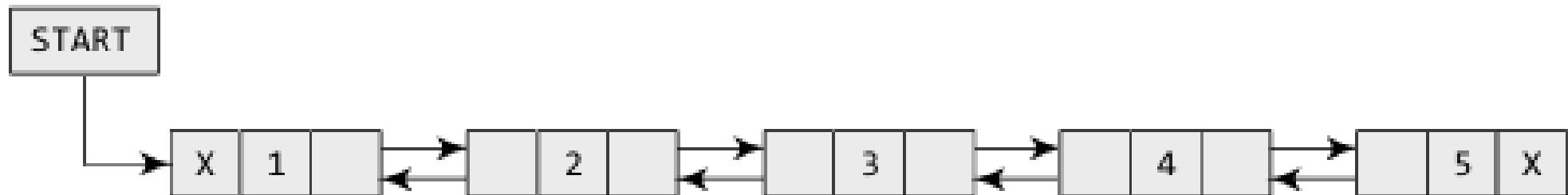
 SET LAST->NEXT = PTR2

[END OF IF]

Step 9: EXIT

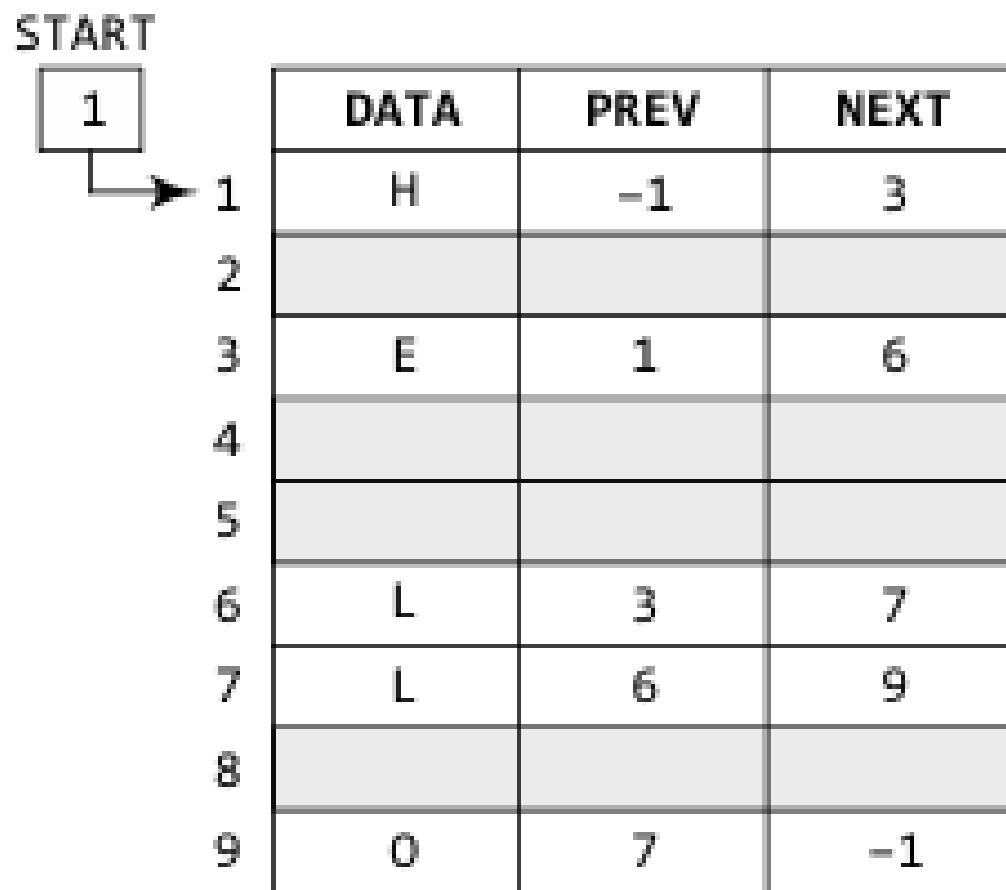
Doubly Linked List

- A doubly linked list or a two-way linked list is a more complex type of linked list which contains a pointer to the next as well as the previous node in the sequence. Therefore, it consists of three parts—data, a pointer to the next node, and a pointer to the previous node



```
struct node
{
    struct node *prev;
    int data;
    struct node *next;
};
```

Memory representation of a doubly linked list



Inserting a new node in a doubly Linked List

Case 1: The new node is inserted at the beginning.

Case 2: The new node is inserted at the end.

Case 3: The new node is inserted after a given node.

Case 4: The new node is inserted before a given node

Inserting a Node at the Beginning of a Doubly Linked List

Suppose we want to add a new node with data 9 as the first node of the list. Then the following changes will be done in the linked list.

Step 1: IF AVAIL = NULL

 Write OVERFLOW

 Go to Step 9

 [END OF IF]

Step 2: SET NEW_NODE = AVAIL

Step 3: SET AVAIL = AVAIL \rightarrow NEXT

Step 4: SET NEW_NODE \rightarrow DATA = VAL

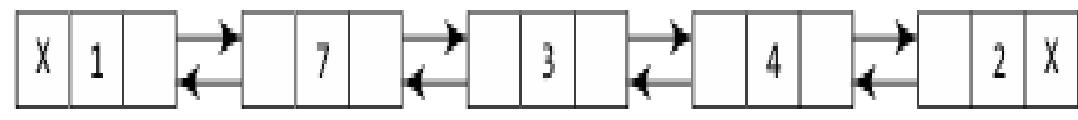
Step 5: SET NEW_NODE \rightarrow PREV = NULL

Step 6: SET NEW_NODE \rightarrow NEXT = START

Step 7: SET START \rightarrow PREV = NEW_NODE

Step 8: SET START = NEW_NODE

Step 9: EXIT

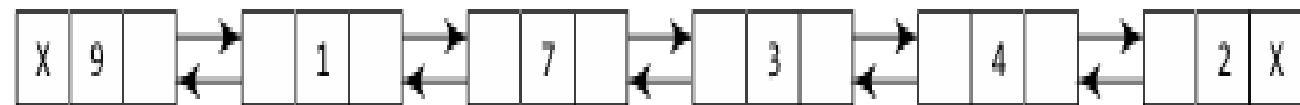


START

Allocate memory for the new node and initialize its DATA part to 9 and PREV field to NULL.



Add the new node before the START node. Now the new node becomes the first node of the list.



START

Inserting a Node at the End end of a Doubly Linked List

```
Step 1: IF AVAIL = NULL  
        Write OVERFLOW  
        Go to Step 11  
    [END OF IF]
```

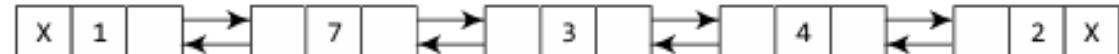
```
Step 2: SET NEW_NODE = AVAIL  
Step 3: SET AVAIL = AVAIL->NEXT  
Step 4: SET NEW_NODE->DATA = VAL  
Step 5: SET NEW_NODE->NEXT = NULL  
Step 6: SET PTR = START  
Step 7: Repeat Step 8 while PTR->NEXT != NULL  
Step 8:     SET PTR = PTR->NEXT  
    [END OF LOOP]  
Step 9: SET PTR->NEXT = NEW_NODE  
Step 10: SET NEW_NODE->PREV = PTR  
Step 11: EXIT
```



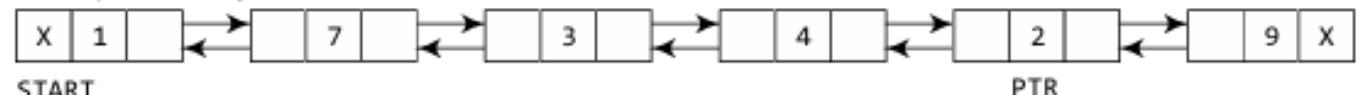
Allocate memory for the new node and initialize its DATA part to 9 and its NEXT field to NULL.



Take a pointer variable PTR and make it point to the first node of the list.

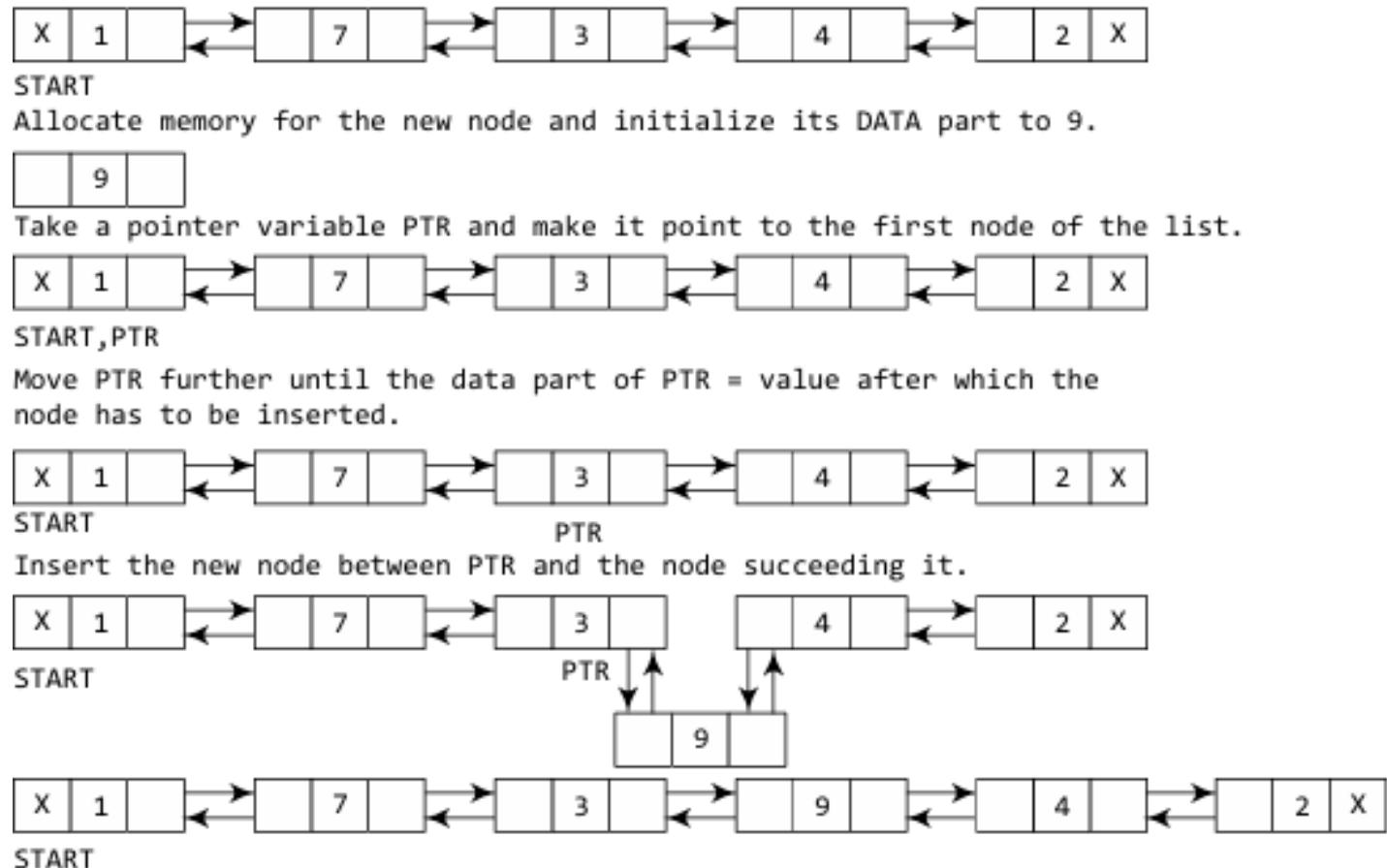


Move PTR so that it points to the last node of the list. Add the new node after the node pointed by PTR.



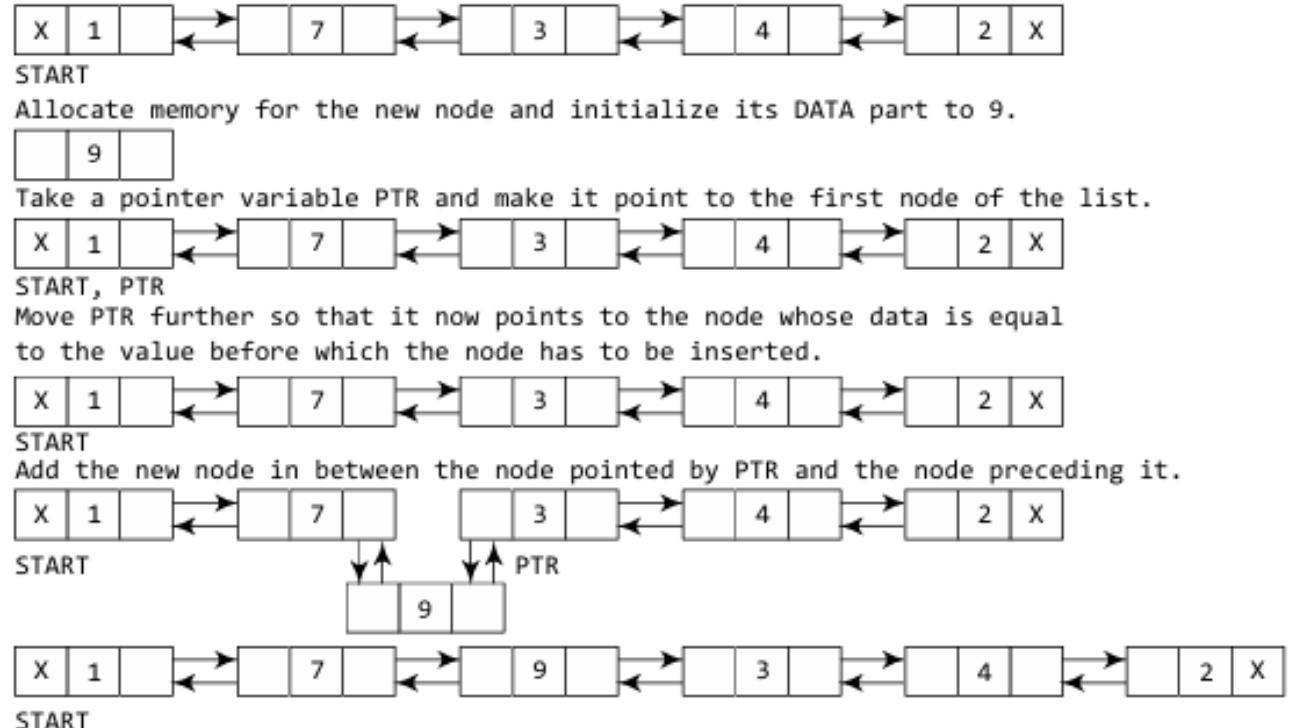
Algorithm to insert a new node after a given node

```
Step 1: IF AVAIL = NULL  
        Write OVERFLOW  
        Go to Step 12  
    [END OF IF]  
Step 2: SET NEW_NODE = AVAIL  
Step 3: SET AVAIL = AVAIL->NEXT  
Step 4: SET NEW_NODE->DATA = VAL  
Step 5: SET PTR = START  
Step 6: Repeat Step 7 while PTR->DATA != NUM  
Step 7:     SET PTR = PTR->NEXT  
    [END OF LOOP]  
Step 8: SET NEW_NODE->NEXT = PTR->NEXT  
Step 9: SET NEW_NODE->PREV = PTR  
Step 10: SET PTR->NEXT = NEW_NODE  
Step 11: SET PTR->NEXT->PREV = NEW_NODE  
Step 12: EXIT
```



Algorithm to insert a new node before a given node

```
Step 1: IF AVAIL = NULL  
        Write OVERFLOW  
        Go to Step 12  
    [END OF IF]  
Step 2: SET NEW_NODE = AVAIL  
Step 3: SET AVAIL = AVAIL -> NEXT  
Step 4: SET NEW_NODE -> DATA = VAL  
Step 5: SET PTR = START  
Step 6: Repeat Step 7 while PTR -> DATA != NUM  
Step 7:     SET PTR = PTR -> NEXT  
    [END OF LOOP]  
Step 8: SET NEW_NODE -> NEXT = PTR  
Step 9: SET NEW_NODE -> PREV = PTR -> PREV  
Step 10: SET PTR -> PREV = NEW_NODE  
Step 11: SET PTR -> PREV -> NEXT = NEW_NODE  
Step 12: EXIT
```



Deleting a node from a doubly Linked List

Case 1: The first node is deleted.

Case 2: The last node is deleted.

Case 3: The node after a given node is deleted.

Case 4: The node before a given node is deleted.

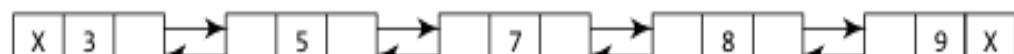
Deleting the First Node from a Doubly Linked List

```
Step 1: IF START = NULL  
        Write UNDERFLOW  
        Go to Step 6  
    [END OF IF]  
Step 2: SET PTR = START  
Step 3: SET START = START -> NEXT  
Step 4: SET START -> PREV = NULL  
Step 5: FREE PTR  
Step 6: EXIT
```



START

Free the memory occupied by the first node of the list and make the second node of the list as the START node.



START

Deleting the Last Node from a Doubly Linked List

```
Step 1: IF START = NULL  
        Write UNDERFLOW  
        Go to Step 7  
    [END OF IF]
```

```
Step 2: SET PTR = START
```

```
Step 3: Repeat Step 4 while PTR->NEXT != NULL
```

```
Step 4:    SET PTR = PTR->NEXT  
    [END OF LOOP]
```

```
Step 5: SET PTR->PREV->NEXT = NULL
```

```
Step 6: FREE PTR
```

```
Step 7: EXIT
```



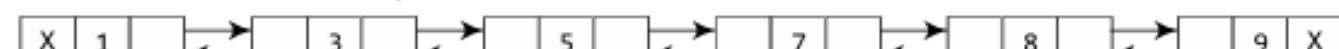
START

Take a pointer variable PTR that points to the first node of the list.



START, PTR

Move PTR so that it now points to the last node of the list.



START

Free the space occupied by the node pointed by PTR and store NULL in NEXT field of its preceding node.



START

Deleting the Node Before a Given Node in a Doubly Linked List

```
Step 1: IF START = NULL  
        Write UNDERFLOW  
        Go to Step 9  
    [END OF IF]  
Step 2: SET PTR = START  
Step 3: Repeat Step 4 while PTR -> DATA != NUM  
Step 4:     SET PTR = PTR -> NEXT  
    [END OF LOOP]  
Step 5: SET TEMP = PTR -> PREV  
Step 6: SET TEMP -> PREV -> NEXT = PTR  
Step 7: SET PTR -> PREV = TEMP -> PREV  
Step 8: FREE TEMP  
Step 9: EXIT
```



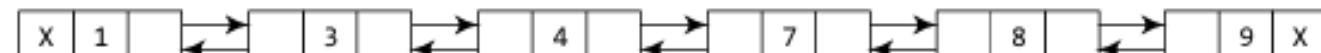
START

Take a pointer variable PTR that points to the first node of the list.



START, PTR

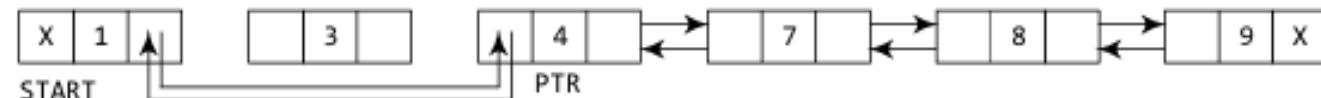
Move PTR further till its data part is equal to the value before which the node has to be deleted.



START

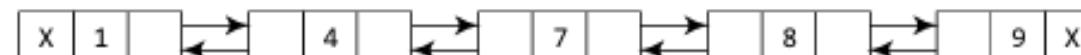
PTR

Delete the node preceding PTR.



START

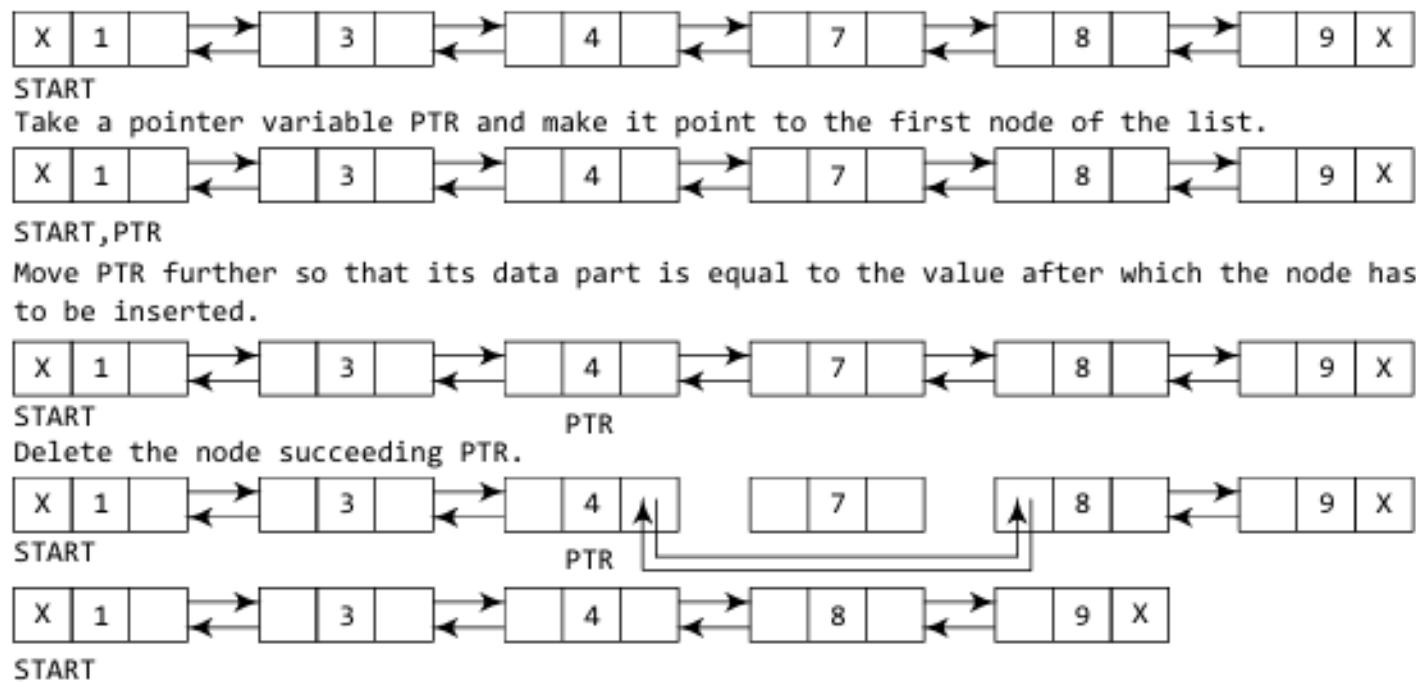
PTR



START

Deleting the Node after a Given Node in a Doubly Linked List

```
Step 1: IF START = NULL  
        Write UNDERFLOW  
        Go to Step 9  
    [END OF IF]  
Step 2: SET PTR = START  
Step 3: Repeat Step 4 while PTR->DATA != NUM  
Step 4:     SET PTR = PTR->NEXT  
    [END OF LOOP]  
Step 5: SET TEMP = PTR->NEXT  
Step 6: SET PTR->NEXT = TEMP->NEXT  
Step 7: SET TEMP->NEXT->PREV = PTR  
Step 8: FREE TEMP  
Step 9: EXIT
```



Applications of LinkedList

- Polynomial representation Let us see how a polynomial is represented in the memory using a linked list. Consider a polynomial $6x^3 + 9x^2 + 7x + 1$. Every individual term in a polynomial consists of two parts, a coefficient and a power.
- 6, 9, 7, and 1 are the coefficients of the terms that have 3, 2, 1, and 0 as their powers respectively. Every term of a polynomial can be represented as a node of the linked list.

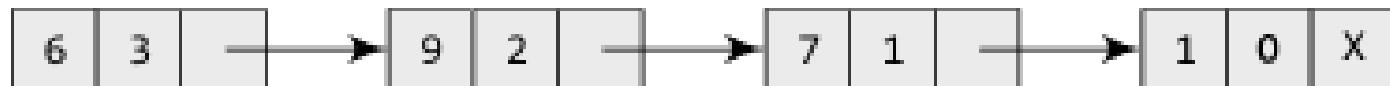


Figure 6.74 Linked representation of a polynomial

Real-World Examples of Linked List Applications

System/Software	Use Case	Type of Linked List Used
Microsoft Word or Google Docs	Undo/Redo functionality	Doubly Linked List
Google Chrome / Firefox	Browser history navigation	Doubly Linked List
Spotify / VLC Media Player	Managing playlists (next/previous track navigation)	Doubly Linked List
Linux Kernel	Process control blocks (scheduling)	Singly / Circular Linked List
Windows File System (NTFS)	Directory structures	Singly Linked List
Facebook Graph API	Social connections & friend lists	Adjacency List using Linked Lists
Redis (In-memory DB)	List datatype for fast data manipulation	Doubly Linked List
Compiler Design Tools	Syntax tree representation	Linked Lists (varies by compiler)
Job Scheduling Systems	Task management and execution order	Circular Linked List
Memory Allocators (malloc)	Free memory block management	Singly Linked List