Data Structure: Linked Lists

Tanvir Ahmed, PhD

Department of Computer Science,

University of Central Florida

Content

- Linked List
  - Types of Linked List
  - Linked Lists Operations
  - Singly Linked List
    - Traversing, Inserting, Deleting
    - Sorted Linked List
  - Doubly Linked List

Linked List

Linked List

- Sequence of connected nodes containing data items.
- Each node contains a connection to another link
- **Second most-used** data structure after array
- Example representation of a Linked List:

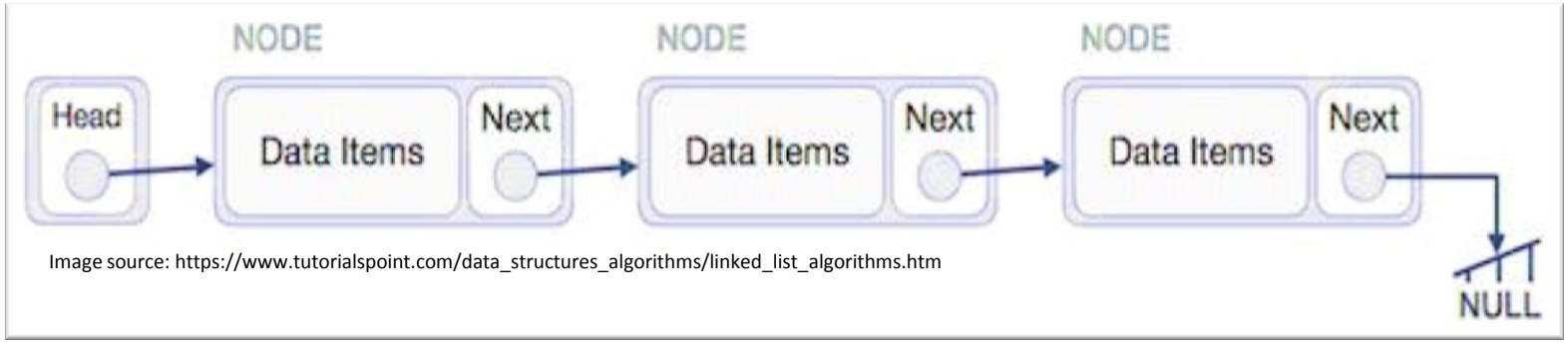


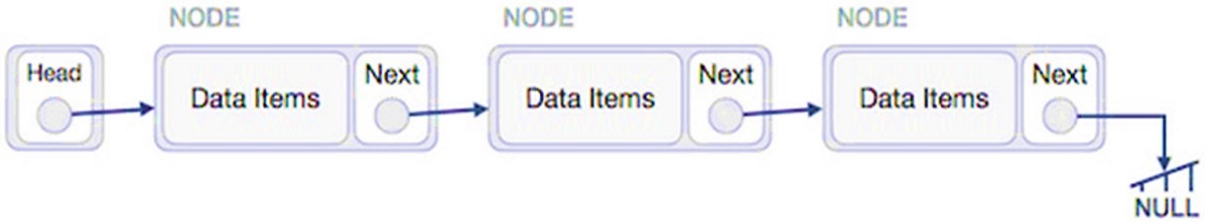
Image source: https://www.tutorialspoint.com/data_structures_algorithms/linked_list_algorithms.htm

Why linked list?

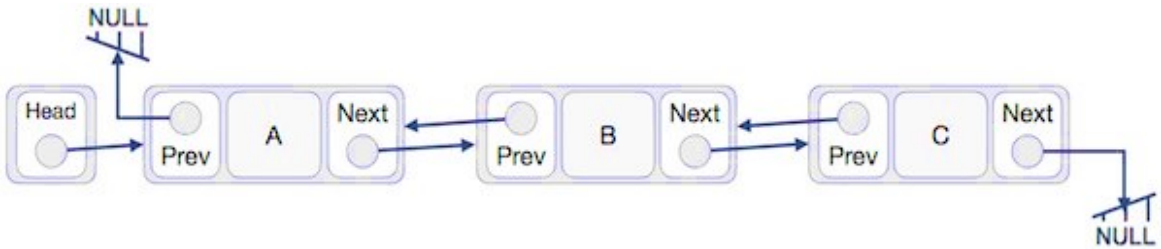
- Why not just use an array?
  - Each node in an array is stored, physically, in contiguous spaces in memory
  - Arrays are fixed size (not dynamic)
  - Inserting and deleting elements is difficult
  - If you have an array of size 1000 and if we want to insert an element after 5^{th} element, all the remaining 995 items must be shifted.
- Why linked list?
  - They are dynamic; length can increase and decrease as necessary.
  - Each node does not necessarily follow the previous one in memory
  - Insertion and deletion is cheap (only need to change few nodes at-most)
- What is negative side of linked list?
  - Getting a particular node may take a large number of operations, as we do not know the address of any individual node

Types of Linked List

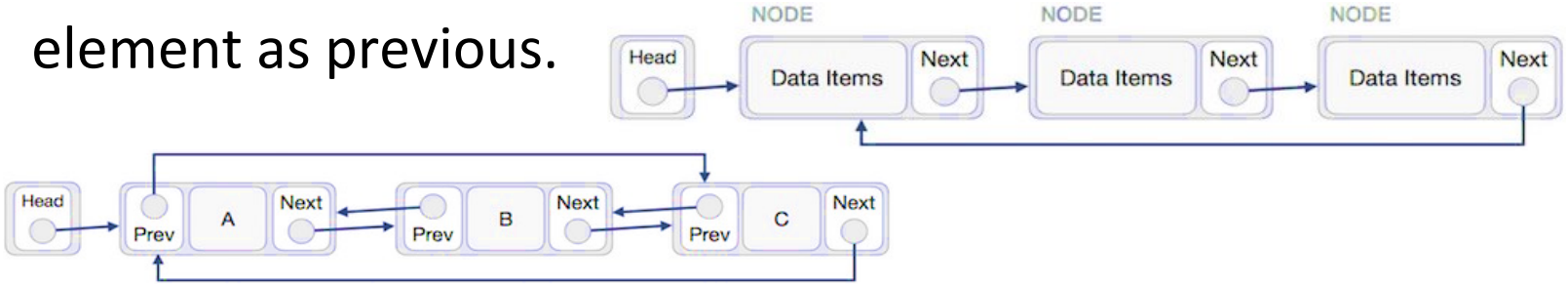
- **Simple/Singly Linked List** - Item navigation is forward only



- **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.



Basic Operations of Linked Lists

- **Insertion** – Adds an element in the list.
- **Deletion** – Deletes a given item from the list.
- **Display** – Displays the complete list in a forward manner.
- **Search** – Search for a given item

Simple/Singly Linked List

Defining a Node

Node

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

- A node has two parts:
  - **info** or known as data, that holds the data you want to store
    - You can store any type of data you want
      - It can be simply an integer or multiple integer, or it can be a string, or it can be even a structure
      - How about you create a playlist? In that case you might want to store song name, artist name, and more other information you want.
  - and **a link** which is a pointer. Known as next. It is a pointer that can point to a Node type variable
    - i.e., it can hold address of a Node

A node with more than one fields

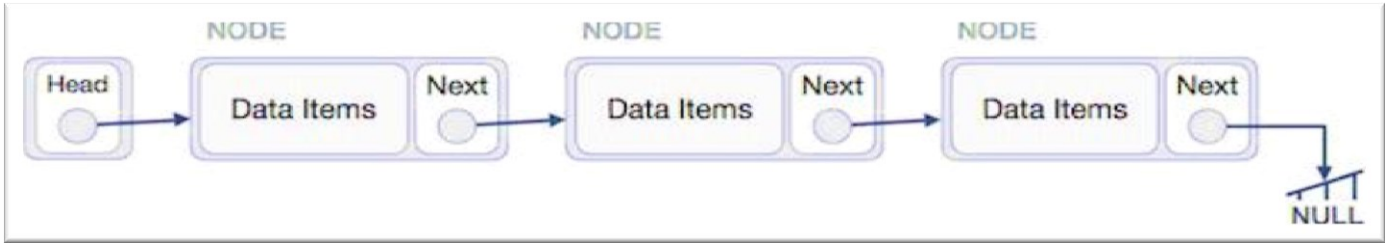
```
struct Book_node
 {
        char name[20];
        char author[8];
        int year;
        struct Book_node *next;
};
```

- The above node has 3 fields for data
- The right side example, has Book as data/info in the linked list's node

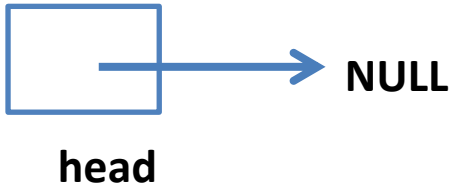
```
struct Book
 {
        char name[20];
        char author[8];
        int year;
};

struct Book_node
 {
        struct Book info;
        struct Book_node *next;
};
```

Head of the list

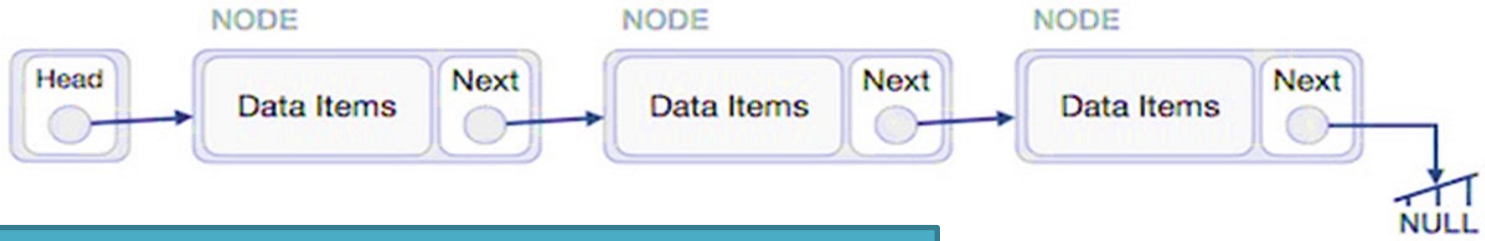


- The first node in the linked list is considered as head.
- A node type pointer is used to keep track of the head
- It is the **most important** node in a linked list.
- If you loss head some how in your code, you will loss your linked list!
- **What is an emptily linked list?**
  - **If head is NULL!**



Traversing a Linked List

- While dealing with linked list, you have to walk through the linked list a lot.
- Traversing means: Traversing/ walking from Head to other nodes and accessing them.
- Many operations require traversing
- Consider the following linked list. The following code snippet can give you an idea how to traverse the list.




```
node *t;

t = head; //assuming Head already initialized

while (t->Next != Null)
    t = t->Next;
```

- Can you modify this code snippet to print only the even data?

- Can you think how to display the info in the Linked List?
- Just add the following statement in the loop:

  printf ("%d ", t->info);

Operations in a Linked List

- Insert a new node
- Delete a node
- Search for a node
- Counting nodes
- Modifying nodes
- and more

Insert into Linked List

You can insert into 3 different places:

1. Beginning of the list
2. End of the list
3. Between nodes in the list

General Steps:

1. Create a temporary node. Fill the “data” and “next”
2. Look for position where to insert
3. Link the temporary node appropriately in the list

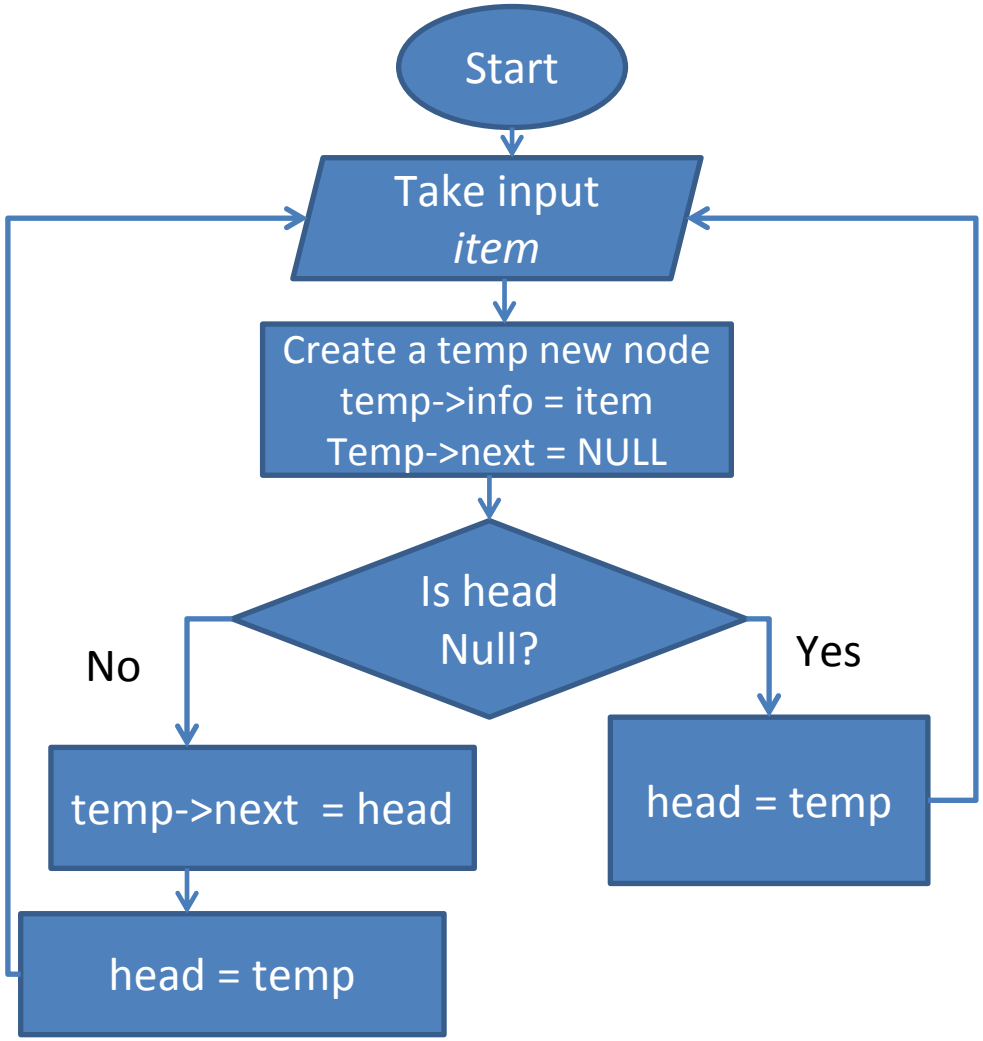
Special Caution:

Always deal with head specially as if you loss or mistake with the head of the linked list, you will mess-up with your list!

Inserting at the Beginning

- There can be many scenario when you might need to insert the node in the front of the list.
  - There can be two situations before insertion
    - The list might be empty. How would you know?
      - Who will be the head after insertion?
    - Or there might be existing node(s) in the list.
      - Who will be head now?
      - Who will be after the head?
      - Let's see in the next slides

Inserting at the Beginning

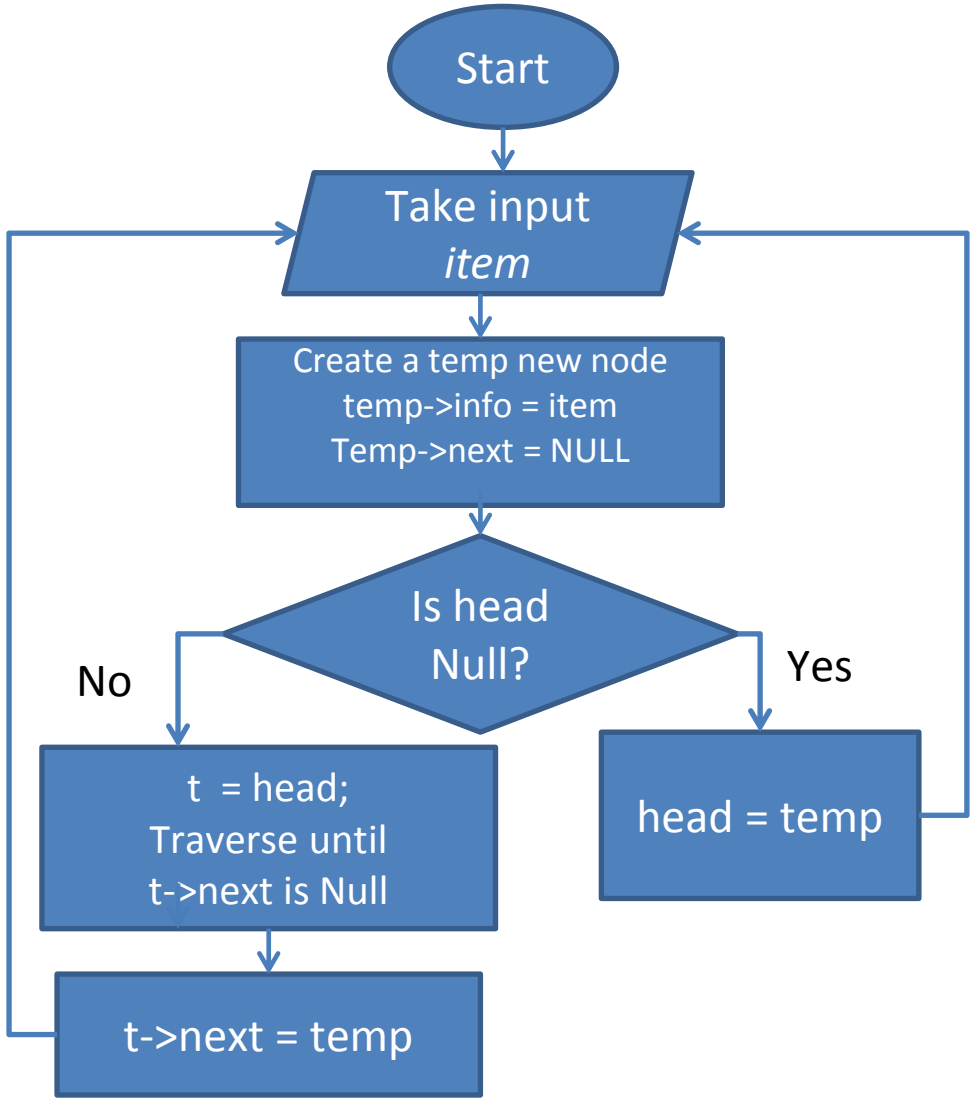



```
Node *head;
void insert_beginning(int item)
{
      node *t;
       node *temp;
       temp=(node *) malloc( sizeof(node);
       temp->info=item;
       temp->next=NULL;
        if(head==NULL)
                  head=temp;
         else
          {
                    temp->next = head;
                     head = temp;
          }
}
```

Inserting at the End

- There can be many scenario when you might need to insert the node in the end of the list.
  - There can be two situations before insertion
    - The list might be empty. How would you know?
      - Who will be the head after insertion?
    - Or there might be existing node(s) in the list.
      - Who will be head now?
      - Who will be after the head?
      - Let's see in the next slides

Inserting at the End




```
node *head;
void insert_end(int item)
{
        node *t;
        node *temp;
        temp=(node *) malloc( sizeof(node);
        temp->info=item;
        temp->next=NULL;
        if(head==NULL)
            head=temp;
        else
        {
            t=head;
            while(t->next!=NULL)
                t=t->next;
            t->next=temp;
        }
}
```

#Now we will see a code example to see how they are implemented

#The code is available in the webcourses.
“SinglyLinkedListInsert_Delete.c”

Inserting Between Nodes

- There can be many scenarios when you might need to insert the node between nodes of the list.
- Example: *Sorted linked list*
- In this case, you might need to:
  - Insert in the beginning or front (if the list is empty or the item is smallest)
    - We have seen how to deal with this
  - Or at the end (the item is largest)
    - We have seen how to deal with this
  - Or between nodes
    - Who will get affected by this operation?
- Remember:
  - Still there can be case that your list might be empty:
    - Who will be the head after insertion?
    - Or there might be existing node(s) in the list.
  - And always take care of your head with special conditions

Inserting Between Nodes

- **Use case: Sorted Linked List.**
- Example of sorted linked list insertion:

a. Insert: 10

b. Insert: 2

c. Insert: 3

d. Insert: 11

- See from the above examples, there can be situations where you might need to insert in the beginning, or to the end, or in between.
- But, all of these insertion is conditional!
  - It means where to insert, it depends the item you are inserting, and the items you already have in the linked list

Inserting Between Nodes

a. Insert 10

b. Insert 2

c. Insert 3

d. Insert 11

- So, while inserting in a sorted linked list, we have to find a position for the node we want to insert.
- As head is always special, can you guess at what scenario you will need to insert the node in the head in the sorted linked list?
- There can be two situations to insert a node in the head:
  - **Either head is null** (example a) or **head's item is greater than item** (example b)
  - See example a and b above.
  - So, just translate it to code:
- If head == NULL or head->info >= item
  - Insert in the beginning. (Example a and b above)
  - You should already know how to insert in the beginning

Inserting Between Nodes

a. Insert 10

b. Insert 2

c. Insert 3

d. Insert 11

- Now, if we find out that the item should not be inserted in the head, what would be the next step?
- **We need to traverse the linked list to find the appropriate place.**
- Now, how long should we travers and how would you know that it is an appropriate place?
- There can be two reason to stop traversing:
  1. Either you find out that you reached to the end of the linked list, because none of the items are larger than the item you want to insert (example d above)
  2. Or you found a node that has larger info than your item (Example c above).
- For case 1, we will stop at the node with 10 (in example d) and then just join our temp node after that. (linking 11 after 10)
- However, for case 2, we have to stop before the node with larger number as we cannot come back if we jump there. So, we look ahead.
  - For example, in example c, we have to stop at 2 so that we can join 3 after 2.

Inserting Between Nodes

a. Insert 10

b. Insert 2

c. Insert 3

d. Insert 11

- So, for the scenario c and d above, the traversal will be like this:

```
t = head;
while (t->Next != NULL && t->next->info <item)
      t = t->Next;
```

- Now after this loop, t stops exactly where we wanted it to stop:
  - At 2 for inserting 3 (example c)
  - And at 10 when inserting 11 (example d)
- Now, how can we join our temp node after them?
- Temp->next will be t->next
- And t-next will be temp

```
temp->next = t->next;
t->next = temp
```

Activity

Write *SortedInsert(int item)* function

Hints from previous slides

- If head is NULL or head->info >= item
  - Insert in the beginning.
- How long should we traverse? Example c and d

```
t = head;
while (t->Next != NULL && t->next->info <item)
    t = t->Next;
```

Insert *temp* after finding the position:

```
temp->next = t->next;   //for last node, temp->next will be NULL
automatically as t->next was NULL
t->next = temp
```

Activity

Write *SortedInsert(int item)* function

Hints from previous slides

- If head is NULL or head->info >= item
  - Insert in the beginning.
- How long should we traverse? Example c and d

```
t = head;
while (t->Next != NULL && t->next->info <item)
    t = t->Next;
```

Insert *temp* after finding the position:

```
temp->next = t->next;
t->next = temp
```

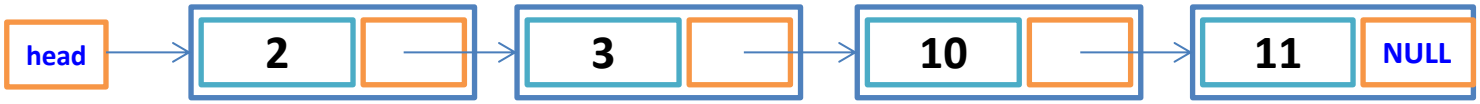
```
node *head;
void Sort_insert(int item)
{
  Node *temp;
  Node *t;
   temp= (node *) malloc(sizeof(node));
   temp->info=item;
   temp->next=NULL;
   if (head==NULL || head->info >=item
   {
        temp->next = head;
        head = temp;
   }
    else
    {
        t = head;
       while (t->Next != NULL && t->next->info <item)
              t = t->Next;
       temp->Next = t->Next;
       t->next = temp
    }
   }
```

Delete Operation

- If you implement stacks and queues using linked list, the delete operations follows the pop and deQueue mechanism
  - Either delete from the head or delete the last node
- However, most cases you will want to delete specific node by searching.
  - So: for deleting, you have to search the node containing the item
  - The node can be in the beginning, // *how would you know that your item is in the beginning?*
    - *head->data == your item*
  - or in the end, // how would you know that?
    - If the node you want to look for has the next as NULL.
  - or in between nodes.
  - While searching for the node, do not jump to the node you want to delete while traversing.
    - Because you want to delete it and how would you join the previous node with the next one as you cannot go back?
      - So, have a look to the data of next node before going there.

Delete operation

- Deletes an item from the linked list



- Delete 2:

```
temp = head;
head = head->next;
free(temp);
return 1;
```

- Delete 12:
- Delete 3:

```
t = head;
while (t->next != NULL && t->next->info != item)
    t = t->next;
If(t->next == NULL ) return 0; //item was not found
temp = t->next;
t->next = t->next->next;
free(temp)
return 1;
```

We have to check the reason of exiting the loop.
If the loop exits for t->next == NULL , then it indicates the item was not found in the list

-In the above illustration, the colors used in the code are matched with the example in the left side

-Now write the function DelList(int item)

Delete Function

```
int DelList(int item)
{
        node *t;
        node *temp;
        if(head==NULL)
                return 0;
        if(head->info==item)
        {
                temp=head;
                head=head->next;
                free(temp);
                return 1;
        }

        t=head;
        while(t->next!=NULL && t->next->info != item)
                t=t->next;
        if(t->next==NULL)
                return 0;
        temp=t->next;
        t->next=t->next->next;
        free(temp);
        return 1;
}
```

How would you implement Search operation?

- Didn't you search the item while deleting?
- Searching is just like traversing the linked list until you find the item you are looking for (if item exists) or until you reach to the end of the linked list (not found).

Linked List Implementation of a Stack

- Implement Stack using Linked List:
  - Where would you push?
    - In the beginning for the linked list (it means you are making head to the new item)
  - Where the items should be deleted from in case of POP?
    - From the head of the linked list
  - What is the condition for empty?

- You already know about both of them. Just implement them at your home.
  - It can be a good exercise.
  - And don’t forget to do this exercise.
  - It should pretty easy if you understood the linked list properly.

Linked List implementation of Queue

- Implement Queue using Linked List
  - Where an enQueue item will be added?
  - Where a dQueue item will be deleted from?
  - What can be the drawback?
    - In case of array based implementation we just need to access one index of the array for both enQueue, and deQueue.
    - We did not need to go through all items for any of the cases
    - However, depending on your implementation, either enQueue or DeQueue any one of them will need to access all the items to reach to the end of the list.
    - O(1) vs O(n) // we will learn about Big-O in another lecture

Linked List implementation of Queue

- Maintaining two pointer can help:
  - One for front of the list
  - One for the back
- One way to think about this is that our struct to store the queue would actually store to pointers to linked list structs.
  - The first would point to the head of the list and
  - the second would always point to the last node in that list.

```
//stores one node of the linked list
struct node {
    int data;
    struct node* next;
};
```

```
// Stores our queue.
struct queue {
        struct node* front;
         struct node* back;
};
```

Linked List implementation of Queue

- **Let's consider how we'd carry out some operations:**

init function: this function should make front and rear of the que as NULL.

enqueue

- **1) Create a new node and store the inserted value into it.**
- **2) Link the back node's next pointer to this new node.**
- **3) Move the back node to point to the newly added node.**

dequeue

- **1) Store a temporary pointer to the beginning of the list**
- **2) Move the front pointer to the next node in the list**
- **3) Free the memory pointed to by the temporary pointer.**

front

- **1) Directly access the data stored in the first node through the front pointer to the list.**

empty

- **1) Check if both pointers (front, back) are null.**

- **A very good exercise for you would be to use the above concepts to implement queue using linked list. You must try it!**

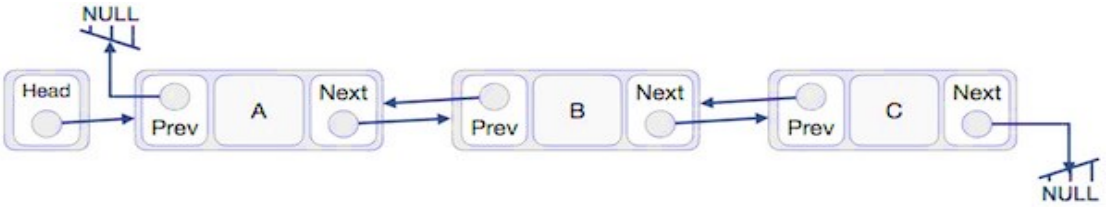
Doubly Linked List

Doubly Linked List

- In case of singly linked list:
  - Can you go back while traversing?
  - What will happen if you write head = head->next?
    - You can't go back to the head
- In doubly linked list: you can go both forward and backward

- **Application Scenario of doubly linked list:**
- A music player which has next and prev buttons.
- The browser cache which allows you to hit the BACK-FORWARD pages.
- Applications that have a Most Recently Used list (a linked list of file names)
- Undo-Redo functionality

Defining a Node

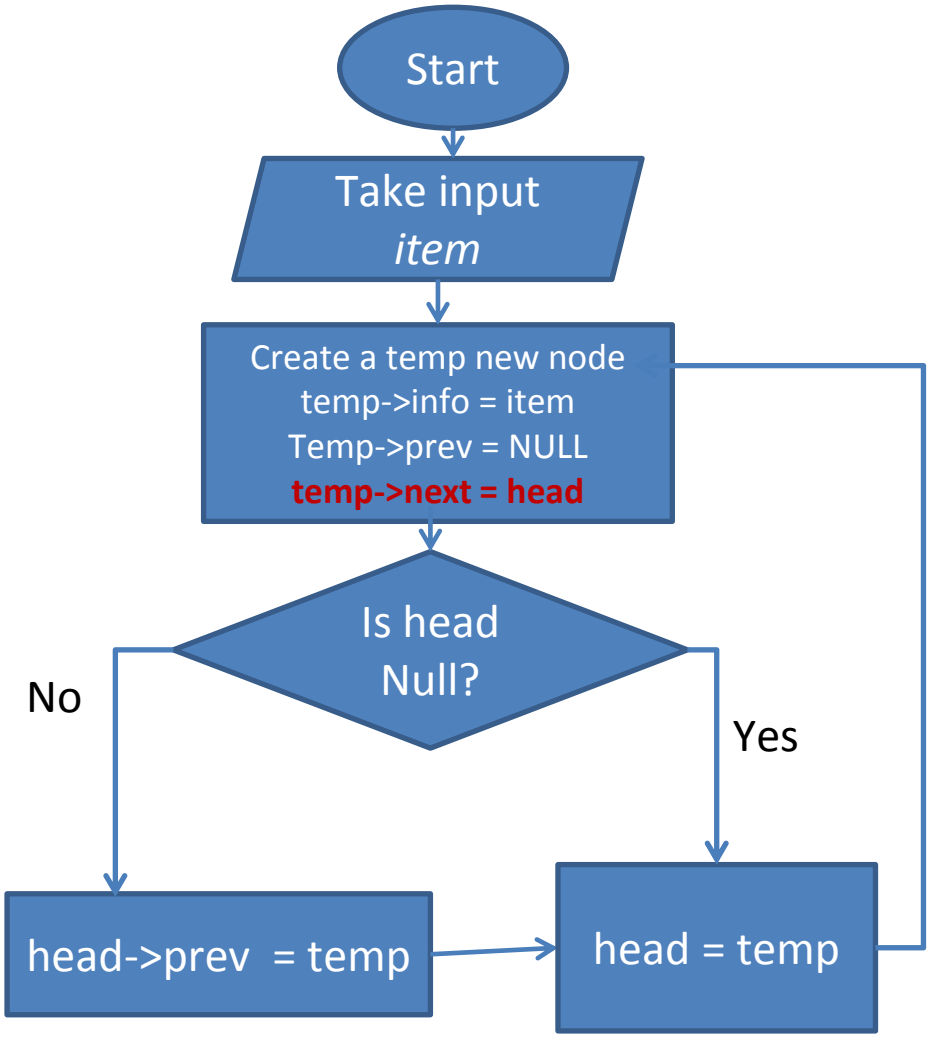


Node

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

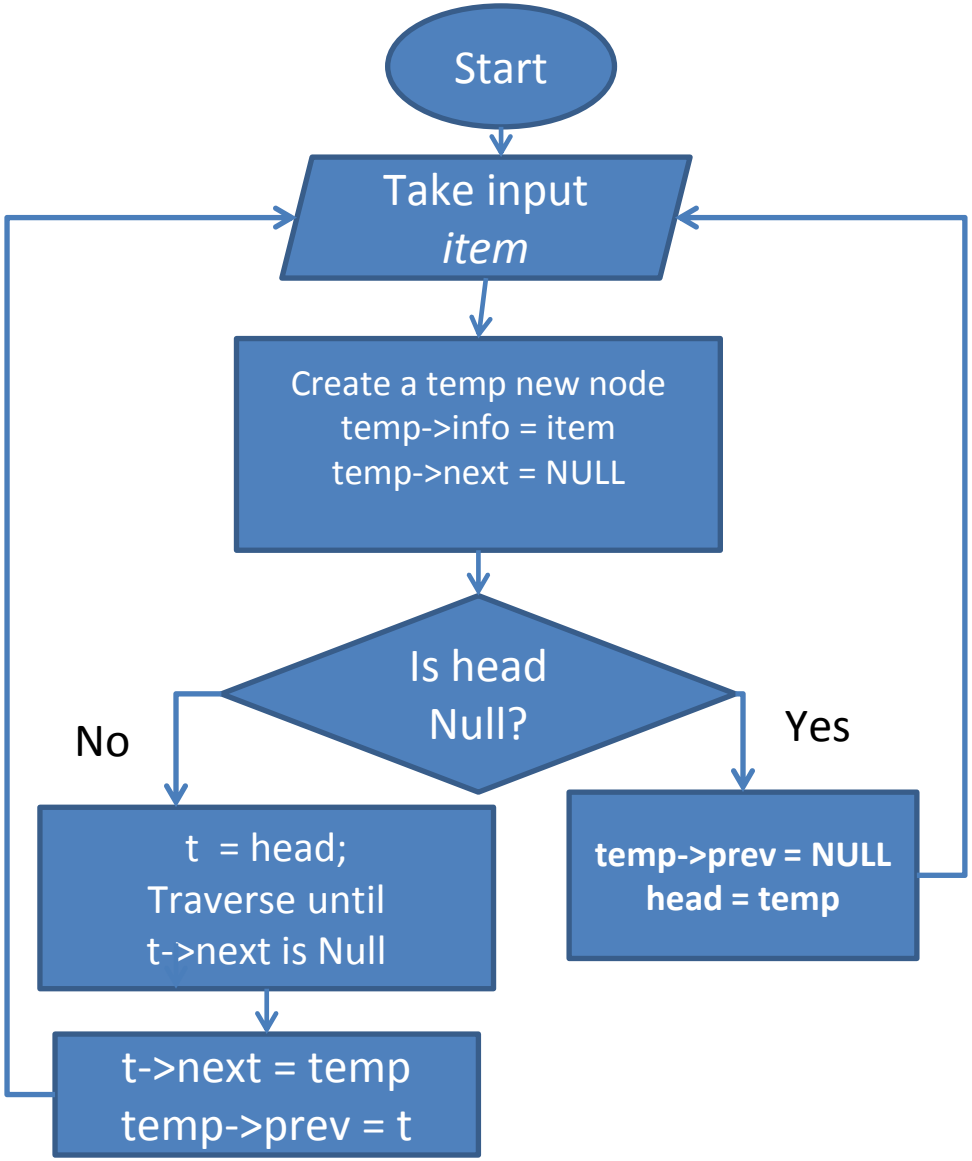
- Info holds the data
- Prev pointer is used to point to previous node
- Next pointer is used to point to the next node

Inserting at the Beginning




```
Node *head;
void insert_beginning(int item)
{
        node *t;
        node *temp;
         temp=(node *) malloc( sizeof(node);
        temp->info=item;
        temp->prev=NULL;
        temp->next=head;
        if(head != NULL)
             head->prev = temp;
         head = temp;
}
```

Inserting at the End




```
node *head;
void insert_end(int item)
{
        node *t;
        node *temp;
        temp=(node *) malloc( sizeof(node));
        temp->info=item;
        temp->next=NULL;
        if(head==NULL)
        {
            temp->prev = NULL;
            head=temp;
        }
        else
        {
             t=head;
             while(t->next!=NULL)
                    t=t->next;
              t->next=temp;
             temp->prev = t;
        }
}
```

Inserting Between Nodes

- Like singly linked list, if you want to create a sorted doubly linked list, you might need to insert it in the beginning or end or between nodes.
  - It requires extra management for prev pointer.
- As always create a new temp node and fill-up the fields.
- Traverse where to insert
- Assign *prev* and *next* of the temp node based on t and t->next
- Adjust *next of t*
- Adjust *prev* of *t->next* (if *t->next is not NULL*)

Exercise

- Write the SortedInsert operation for Doubly Linked List
  - The hints already provided in previous slide
  - Also take help from SortedInsert function of Singly Linked List.

Delete operation

#similar to singly linked list, with some additional condition to adjust prev

```
int DelListDoubly(int item)
{
        node *t;
        node *temp;
        if(head==NULL)
                return 0;
        if(head->info==item)
        {
                temp=head;
                head=head->next;
                if (head != NULL) //new condition for doubly
                    head -> prev = NULL;
                free(temp);
                return 1;
        }
        t=head;
        while(t->next!=NULL && t->next->info != item)
                t=t->next;
        if(t->next==NULL)
                return 0;
        temp=t->next;
        t->next=t->next->next;
        if (t->next)            //new condition for doubly
            t->next->prev = t;
        free(temp);
        return 1;
}
```

Circular Linked List

- For a circular linked list:
  - How would you know you are in the end of the list?
  - The last element should point to the head (instead of NULL)

Summary

- Linked List
- Linked List Operations
- Sorted Linked List
- During the lecture we explain most of the codes by scratching in papers.
  - Scratching various situations would really help to map them to code.

Question?

Thank you ☺