Subject: Data structures using C
Topic : Linked list
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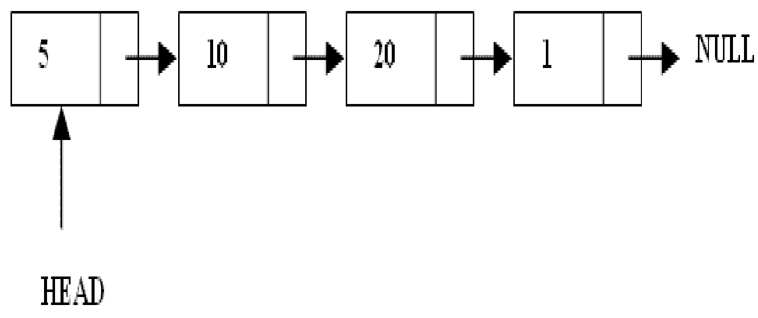
Academic year:2020-2021

What are Linked Lists

- A linked list is a linear data structure.
- Nodes make up linked lists.
- Nodes are structures made up of data and a pointer to another node.
- Usually the pointer iscalled next.



Arrays Vs Linked Lists

Arrays	**Linked list**
Fixed size: Resizing is expensive	Dynamic size
Insertions and Deletions are inefficient: Elements are usually shifted	Insertions and Deletions are efficient: No shifting
Random access i.e., efficient indexing	No random access → Not suitable for operations requiring accessing elements by index such as sorting
No memory waste if the array is full or almost full; otherwise may result in much memory waste.	Since memory is allocated dynamically(acc. to our need) there is no waste of memory.
Sequential access is faster [Reason: Elements in contiguous memory locations]	Sequential access is slow [Reason: Elements not in contiguous memory locations]

Types of lists

- There are two basic typesof linked list

- Singly Linked list

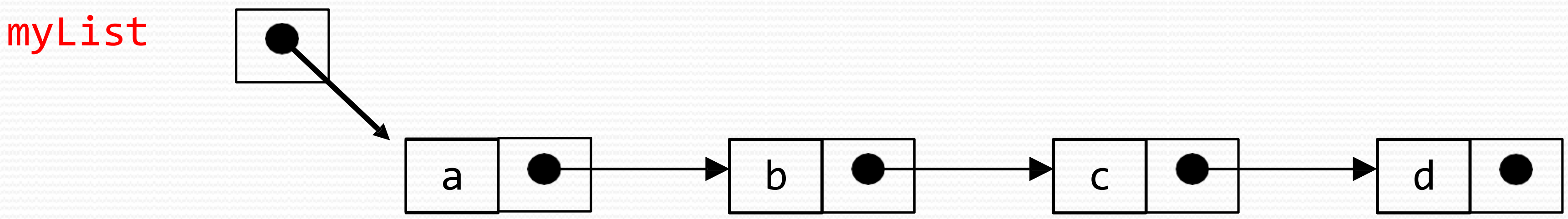
- Doubly linked list

Singly Linked List

- Each node has only one link part
- Each link part contains the address of the next node in the list
- Link part of the last node contains NULL value which signifies the end of the node

Schematic representation

- Here is a singly-linked list (SLL):



•Each node contains a value(data) and a pointer to the next node in the list

• myList is the header pointer which points at the first node in the list

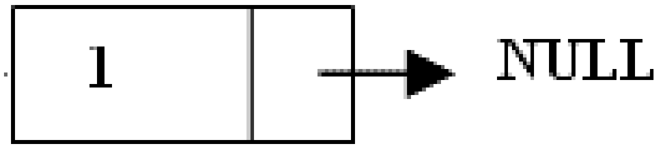
Basic Operations on a list

- Creating a List
- Inserting an element in a list
- Deleting anelement from a list
- Searching a list
- Reversing a list

Creating a node

```
struct node{
        int data;                    // A simple node of a linked list
        node*next;
    }*start;                         //start  points at the first node
start=NULL ;                           initialised to NULL at beginning
```

```
node* create( int num) //say num=1 is passed from main
{
   node*ptr;
   ptr= new  node;  //memory allocated dynamically
        if(ptr==NULL)
          'OVERFLOW' // no memory available
           exit(1);
        else
        {
           ptr->data=num;
           ptr->next=NULL;
           return ptr;
        }
 }
```



To be called from main() as:-

```
void main()
{
    node* ptr;
    int data;
    cin>>data;
    ptr=create(data);
}
```

Inserting the node in a SLL

There are 3 cases here:-

- Insertion at the beginning
- Insertion at the end
- Insertion after a particular node

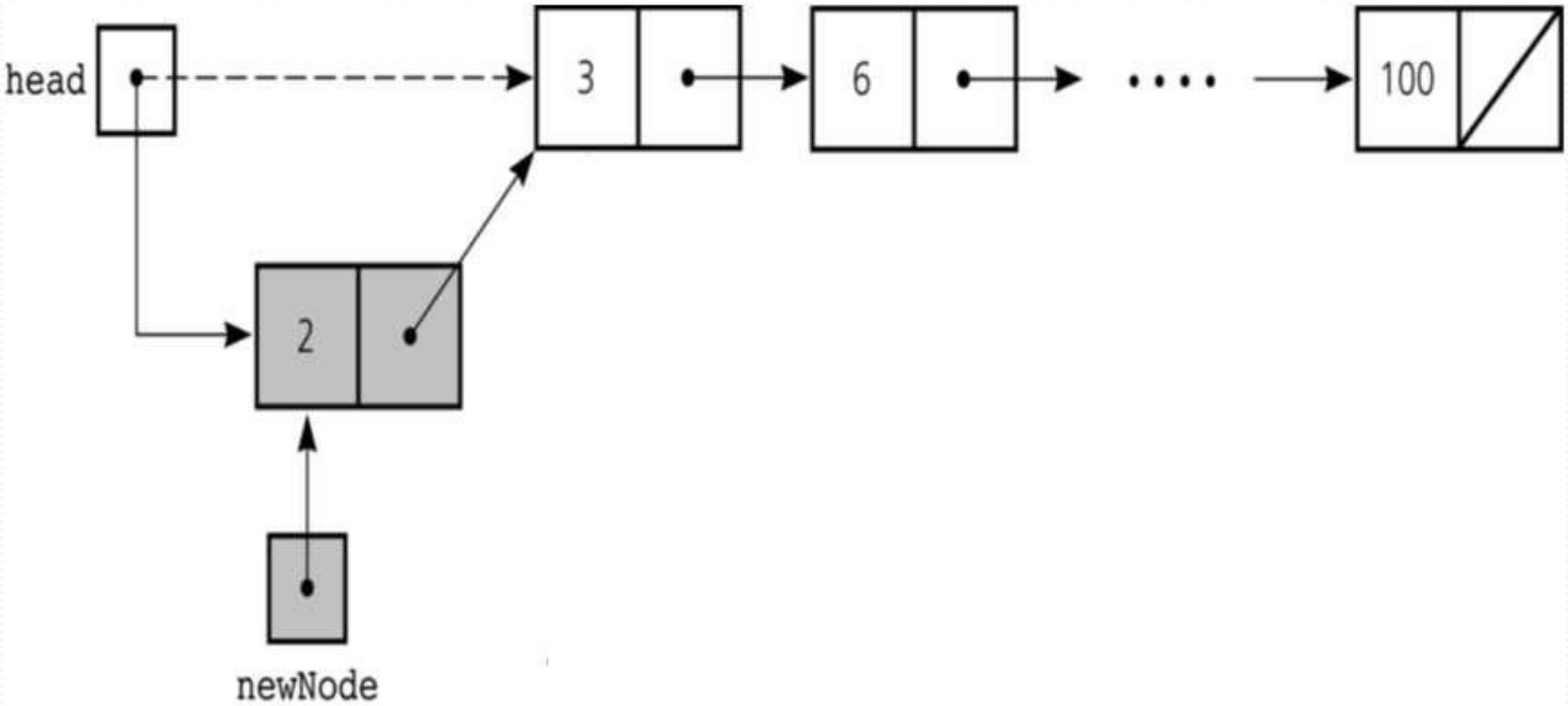
Insertion at the beginning

There are two steps to be followed:-

a) Make the next pointer of the node point towards the first node of the list

b) Make the start pointer point towards this new node

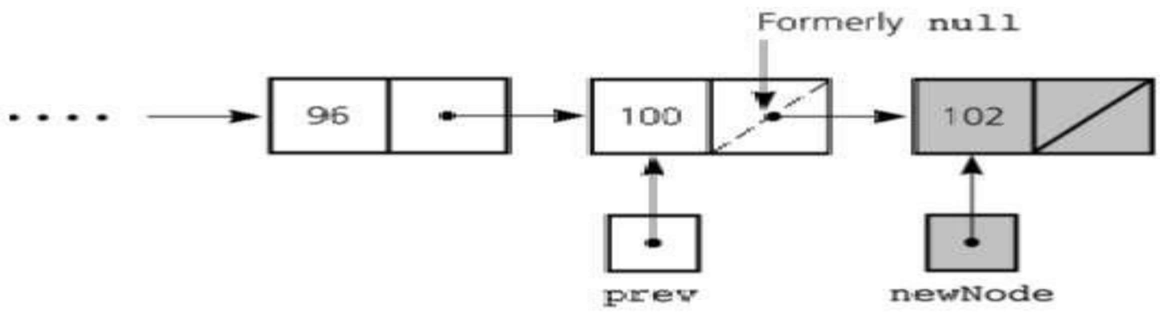
- If the list is empty simply make the start pointer point towards the new node;


head
3
6
100
2
newNode

```
void insert_beg(node* p)
{
node* temp;
            if(start==NULL)    //if the list is empty
           {
              start=p;
              cout<<"\nNode inserted successfully at the
                          beginning";
           }
          else {
                  temp=start;
                  start=p;
                  p->next=temp;  //making new node point at
                }                    the first node of the list
}
```

Inserting at the end

Here we simply need to make the next pointer of the last node point to the new node



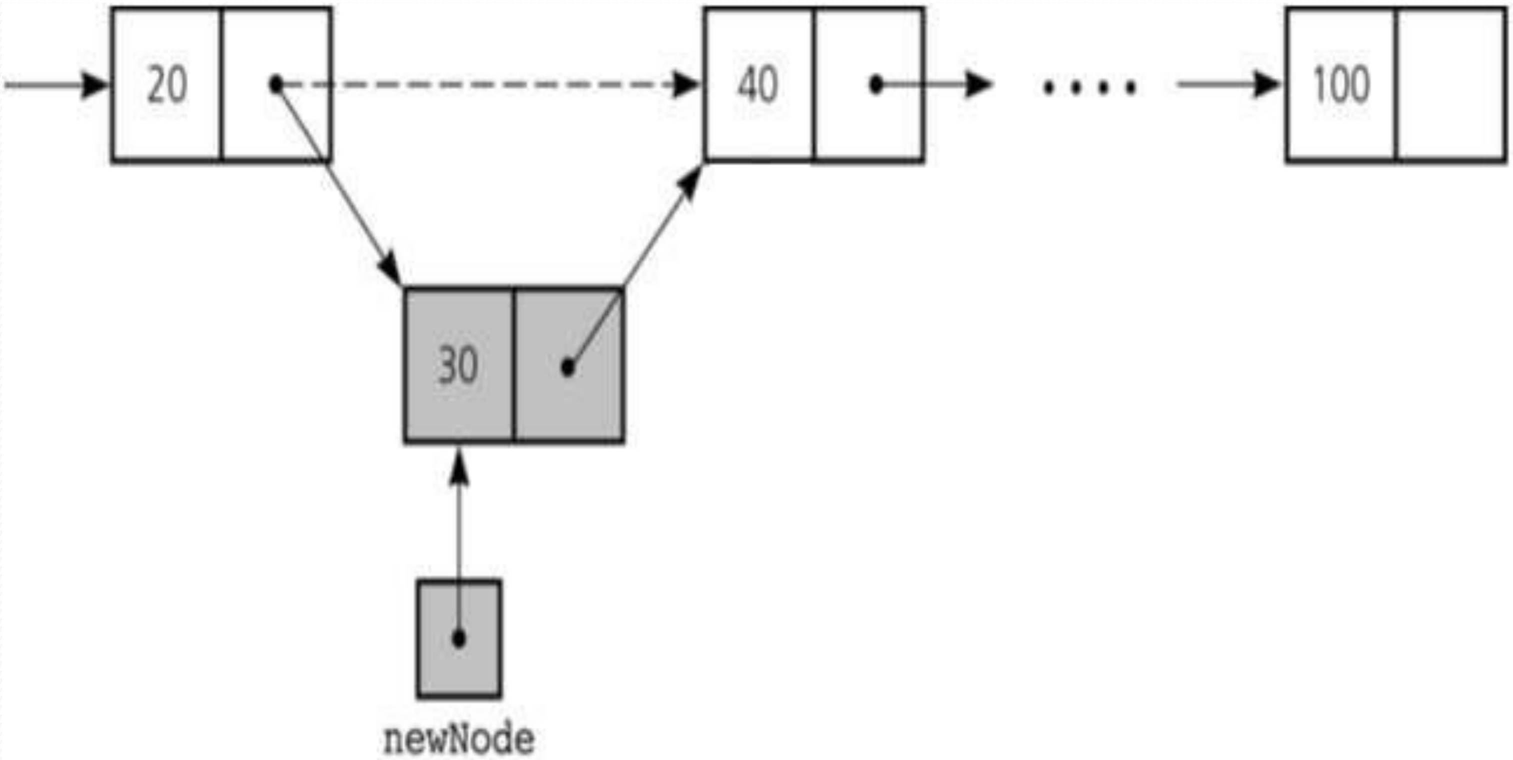
```
void insert_end(node* p)
{
node *q=start;
        if(start==NULL)
        {
          start=p;
          cout<<"\nNode inserted successfully at theend...!!!\n";
        }
     else{
                while(q->link!=NULL)
                  q=q->link;
            q->next=p;
           }
}
```

Inserting after an element

Here we again need to do 2 steps :-

- Make the next pointer of the node to be inserted point to the next node of the node after which you want to insert the node

- Make the next pointer of the node after which the node is to be inserted, point to the node to be inserted



20
40
....
100
30
newNode

```
void insert_after(int c,node* p)
{
node* q;
q=start;
        for(int i=1;i<c;i++)
       {
          q=q->link;
                 if(q==NULL)
                cout<<"Less than "<<c<<" nodes in the list...!!!";
       }
 p->link=q->link;
 q->link=p;
cout<<"\nNode inserted successfully";
}
```

Deleting a node in SLL

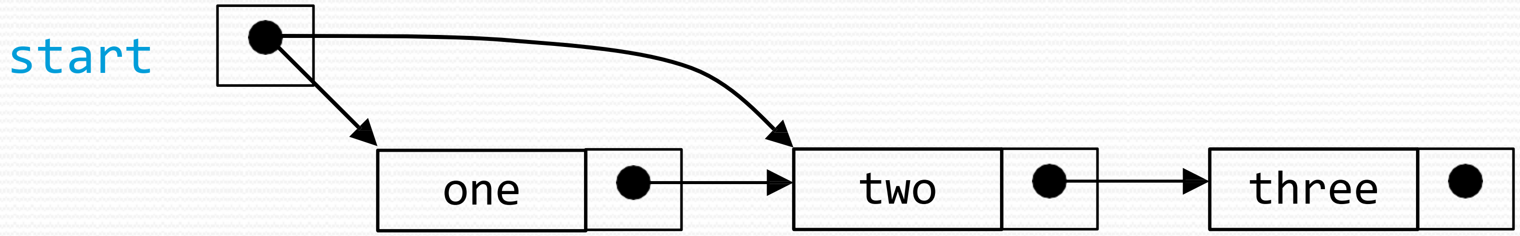
Here also we have threecases:-

- Deleting the first node
- Deleting the last node
- Deleting the intermediate node

Deleting the first node

Here we apply 2 steps:-

- Making the start pointer point towards the 2nd node
- Deleting the first node using delete keyword

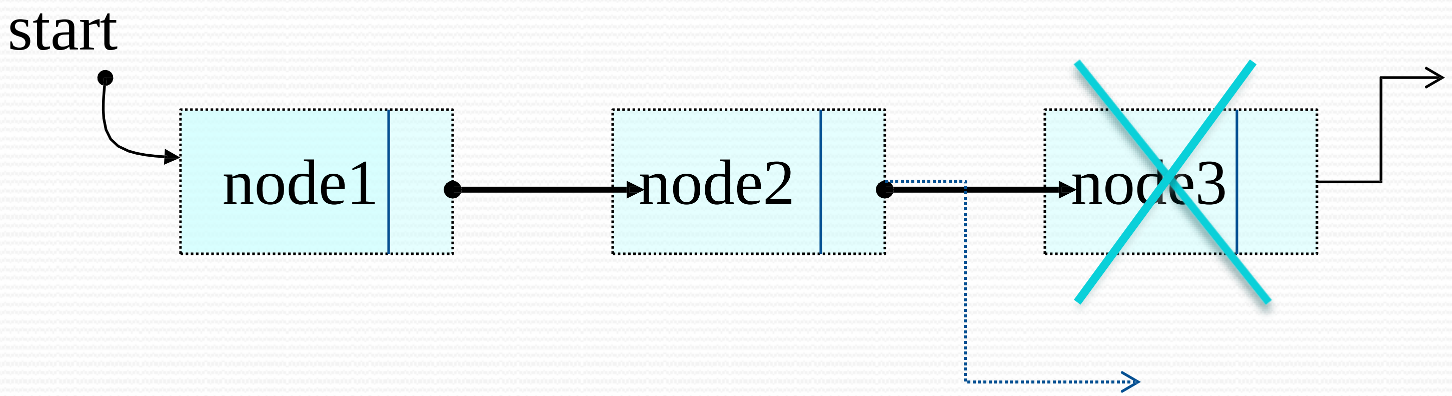


```
void del_first()
{
     if(start==NULL)
    cout<<"\nError......List is empty\n";
    else
    {
      node*  temp=start;
      start=temp->link;
      delete temp;
cout<<"\nFirst node deleted successfully....!!!";
    }
}
```

Deleting the last node

Here we apply 2 steps:-

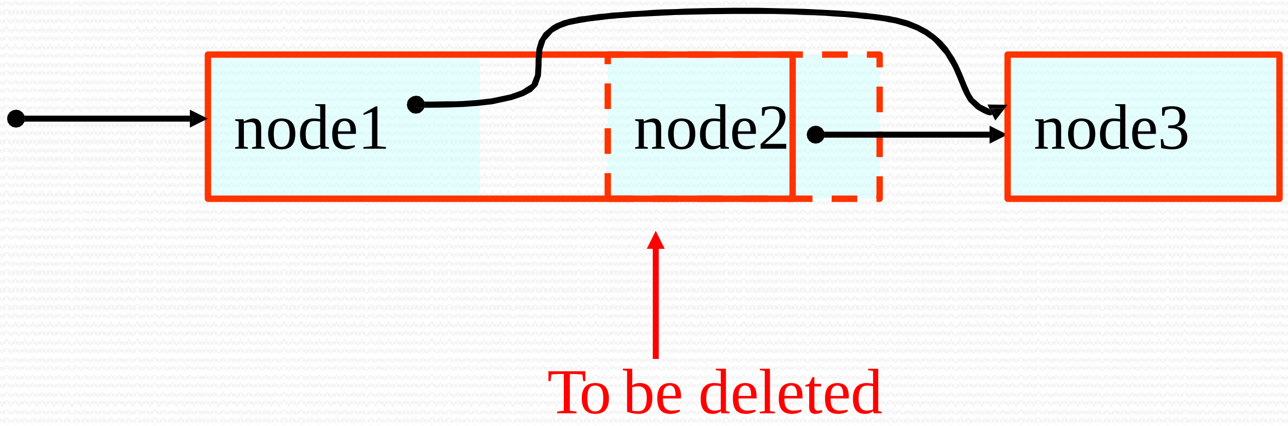
- Making the second last node's next pointerpoint to NULL
- Deleting the last node viadelete keyword



```
void del_last()
{
	if(start==NULL)
	cout<<"\nError....List is empty";
	else
		{
		  node* q=start;
			while(q->link->link!=NULL)
			 q=q->link;
		  node* temp=q->link;
		  q->link=NULL;
		  delete temp;
		  cout<<"\nDeleted successfully...";
		}
	}
}
```

Deleting a particular node

Here we make the next pointer of the node previous to the node being deleted ,point to the successor node of the node to be deleted and then delete the node using delete keyword



```
void del(int c)
{
node* q=start;
    for(int i=2;i<c;i++)
    {
     q=q->link;
         if(q==NULL)
         cout<<"\nNode not found\n";
    }
    if(i==c)
    {
     node* p=q->link;        //node to be deleted
    q->link=p->link;      //disconnecting the node p
    delete p;
    cout<<"Deleted Successfully";
    }
}
```

Searching a SLL

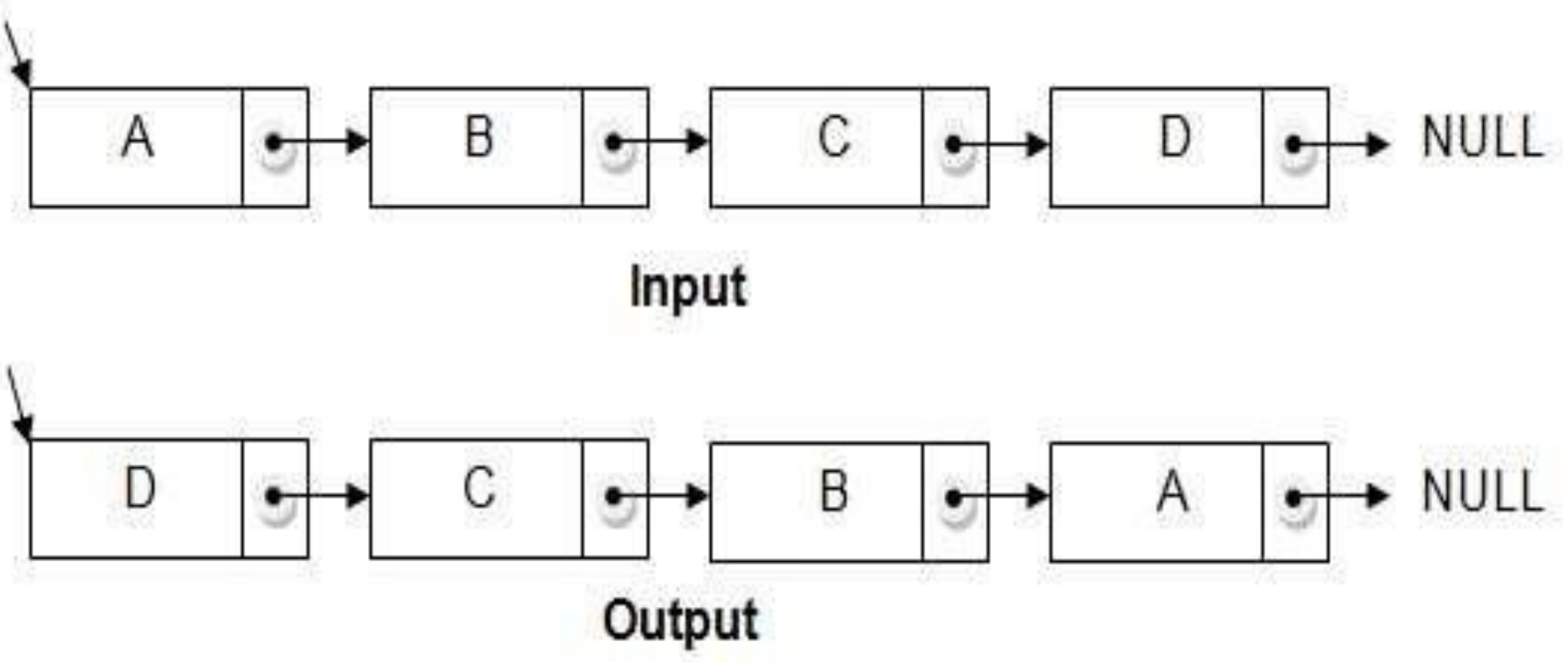
- Searching involves finding the required element in the list
- We can use various techniques of searching like linear search or binary search where binary search is more efficient in case of Arrays
- But in case of linked list since random access is not available it would become complex to do binary search in it
- We can perform simple linear search traversal

In linear search each node is traversed till the data in the node matches with the required value

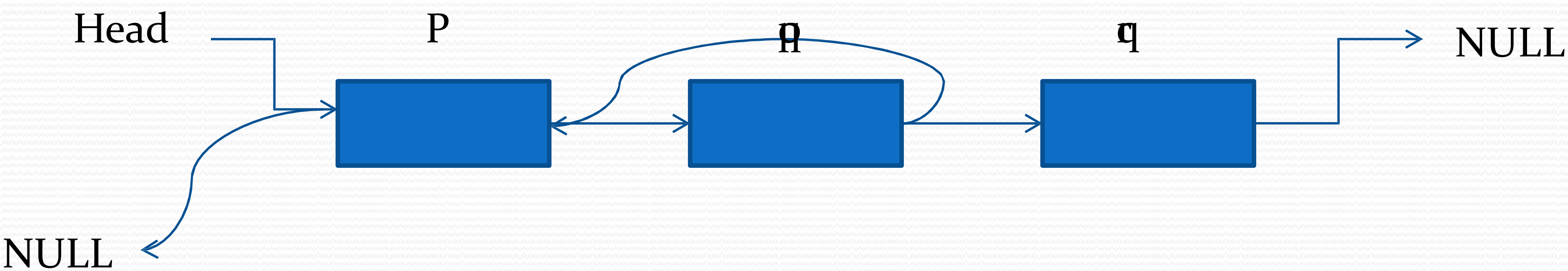
```
void search(int x)
{
  node*temp=start;
    while(temp!=NULL)
      {
         if(temp->data==x)
          {
            cout<<"FOUND "<<temp->data;
            break;
          }
        temp=temp->next;
      }
}
```

Reversing a linked list

- We can reverse a linked list by reversing the direction of the links between 2 nodes



- We make use of 3 structure pointers say p,q,r
- At any instant q will point to the node next to p and r will point to the node next to q



- For next iteration p=q and q=r
- At the end we will change head to the last node

Code

```
void reverse()
{
node*p,*q,*r;
    if(start==NULL)
    {
     cout<<"\nList is empty\n";
     return;
    }
p=start;
q=p->link;
p->link=NULL;
   while(q!=NULL)
   {
    r=q->link;
    q->link=p;
    p=q;
    q=r;
   }
   start=p;
   cout<<"\nReversed successfully";
}
```

COMPLEXITY OF VARIOUS OPERATIONS IN ARRAYS AND SLL

Operation	**ID-Array Complexity**	**Singly-linked list Complexity**
Insert at beginning	O(n)	O(1)
Insert at end	O(1)	O(1) if the list has **tail** reference O(n) if the list has no **tail** reference
Insert at middle	O(n)	O(n)
Delete at beginning	O(n)	O(1)
Delete at end	O(1)	O(n)
Delete at middle	O(n): O(1) access followed by O(n) shift	O(n): O(n) search, followed by O(1) delete
Search	O(n) linear search O(log n) Binary search	O(n)
Indexing: What is the element at a given position k?	O(1)	O(n)

Doubly Linked List

1. **Doubly linked list** is a linked data structure that consists of a set of sequentially linked records called nodes.

2 . Each node contains three fields ::

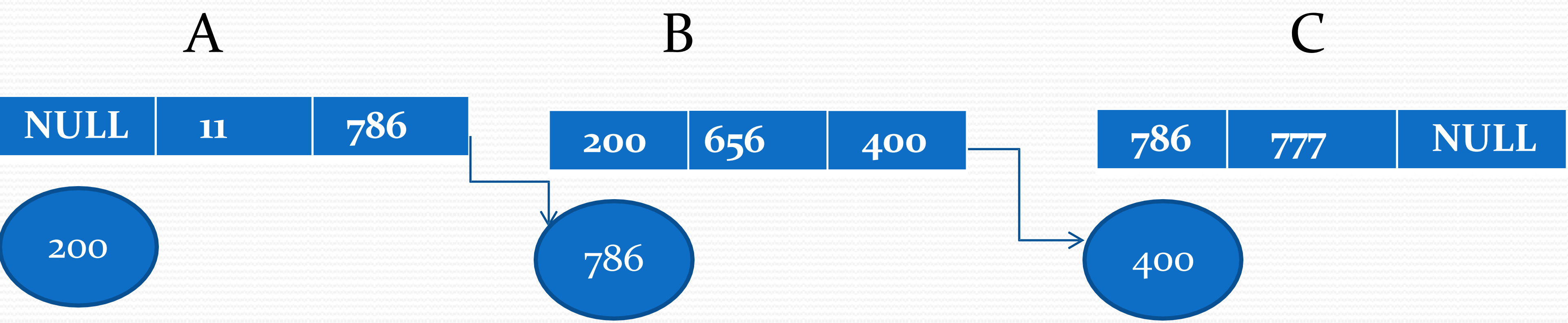
-: one is data part which contain data only.

-:two other field is links part that are point or references to the previous or to the next node in the sequence of nodes.

3. The beginning and ending nodes' **previous** and **next** links, respectively, point to some kind of terminator, typically a sentinel node or null to facilitate traversal of the list.

NODE

previous	data	next



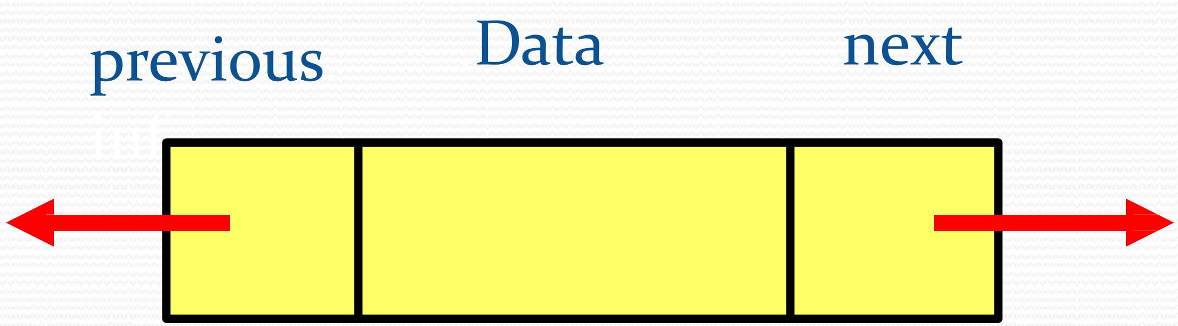
A doubly linked list contain three fields: an integer value, the link to the next node, and the link to the previous node.

DLL's compared to SLL's

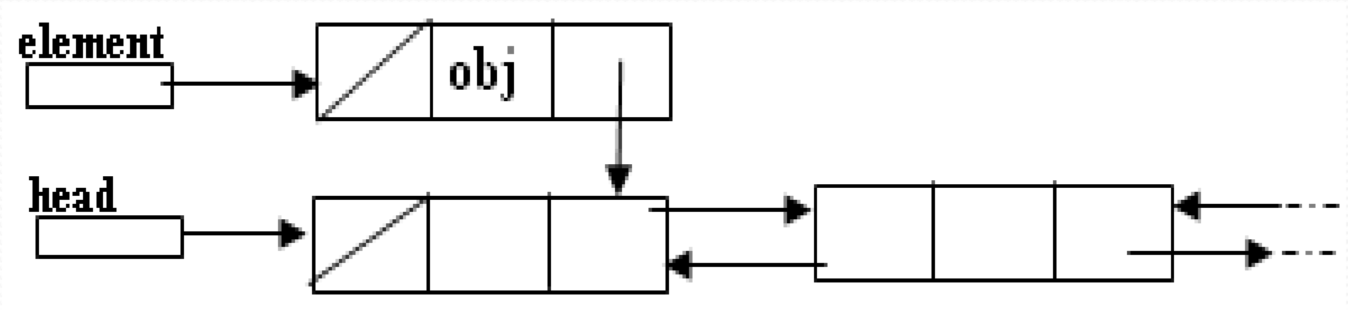
- Advantages:
  - Can be traversed in either direction (may be essential for some programs)
  - Some operations, such as deletion and inserting before a node, become easier
- Disadvantages:
  - Requires more space
  - List manipulations are slower (because more links must be changed)
  - Greater chance of having bugs (because more links must be manipulated)

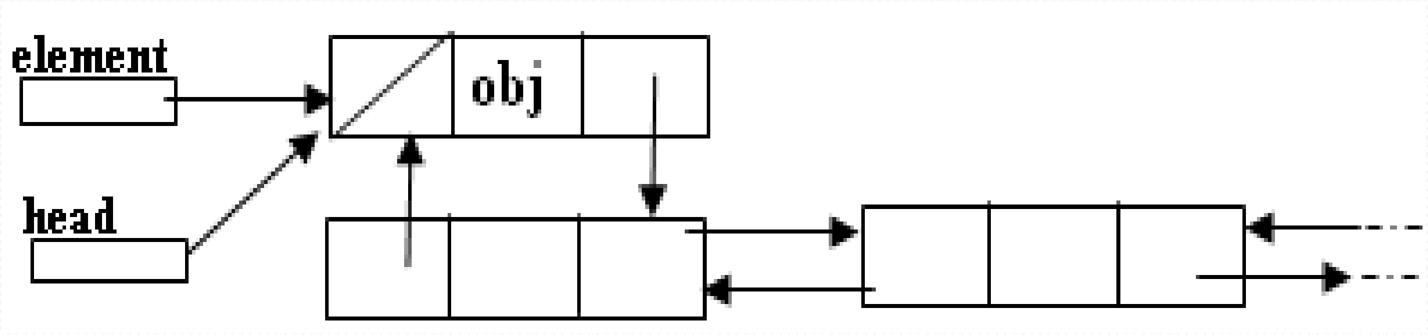
Structure of DLL

```
struct node
{
  int data;
  node*next;
  node*previous;   //holds the address of previous node
};
```



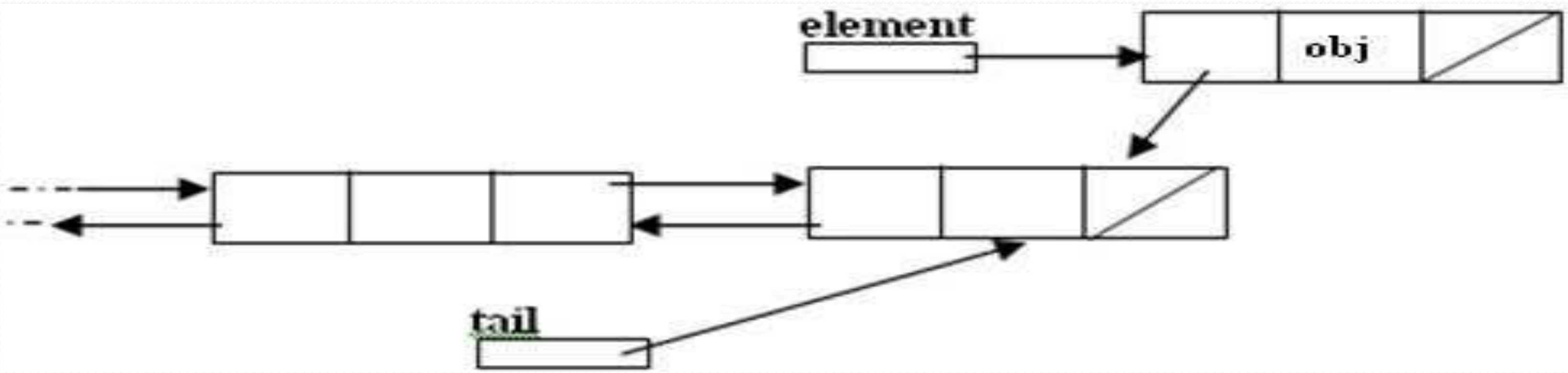
Inserting at beginning

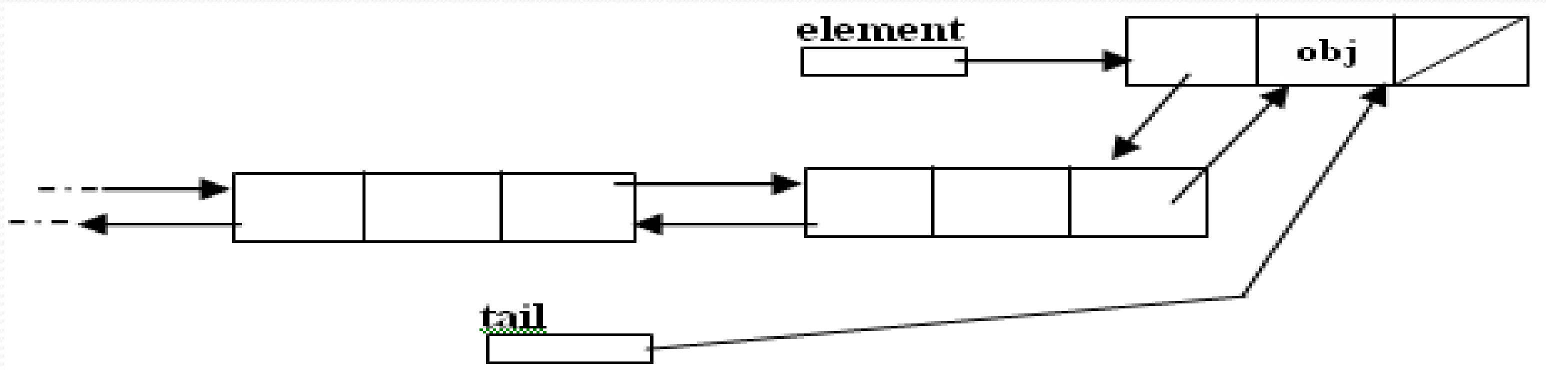




```
void insert_beg(node *p)
{
  if(start==NULL)
  {
    start=p;
    cout<<"\nNode inserted successfully at the beginning\m";
  }
  else
  {
  node* temp=start;
  start=p;
  temp->previous=p;     //making 1st node's previous point to the
   new node
  p->next=temp;         //making next of the new node point to the
   1st node
  cout<<"\nNode inserted successfully at the beginning\n";
  }
```

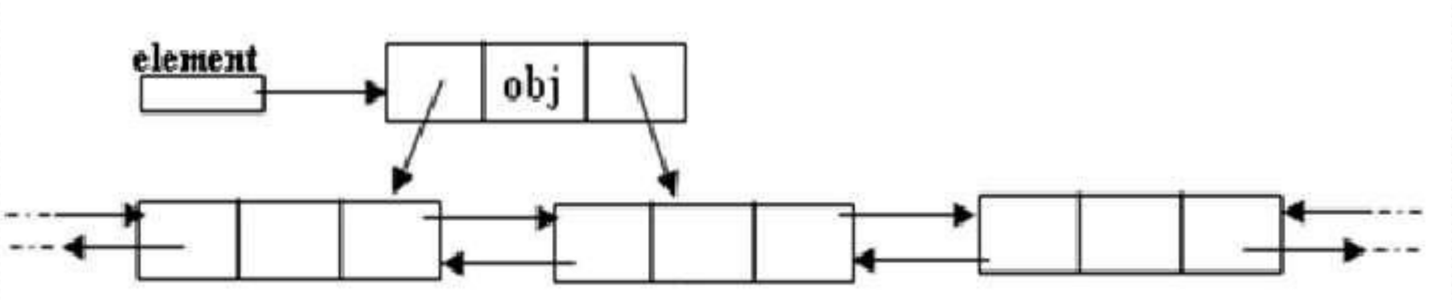
Inserting at the end



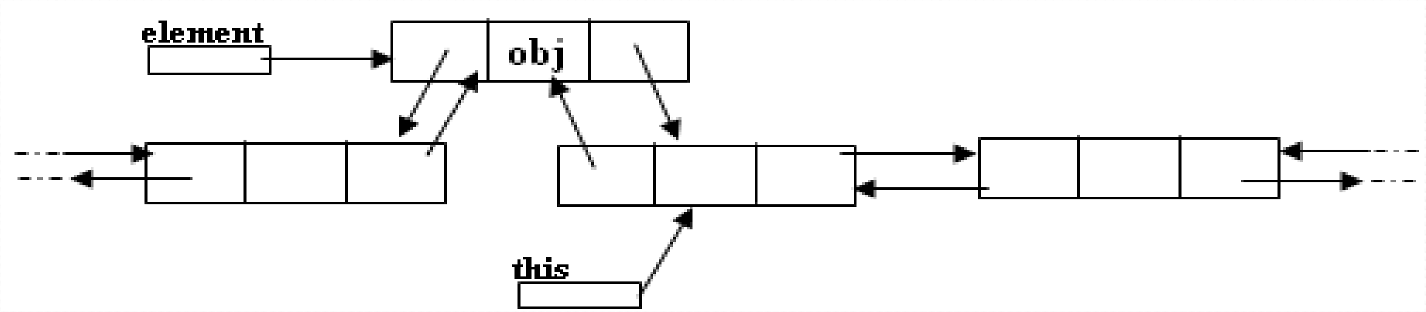


```
void insert_end(node* p)
{
    if(start==NULL)
    {
    start=p;
    cout<<"\nNode inserted successfully at the end";
    }
    else
    {
     node* temp=start;
      while(temp->next!=NULL)
      {
      temp=temp->next;
      }
     temp->next=p;
     p->previous=temp;
     cout<<"\nNode inserted successfully at the end\n";
    }
}
```

Inserting after a node



Making next and previous pointer of the node to be inserted point accordingly

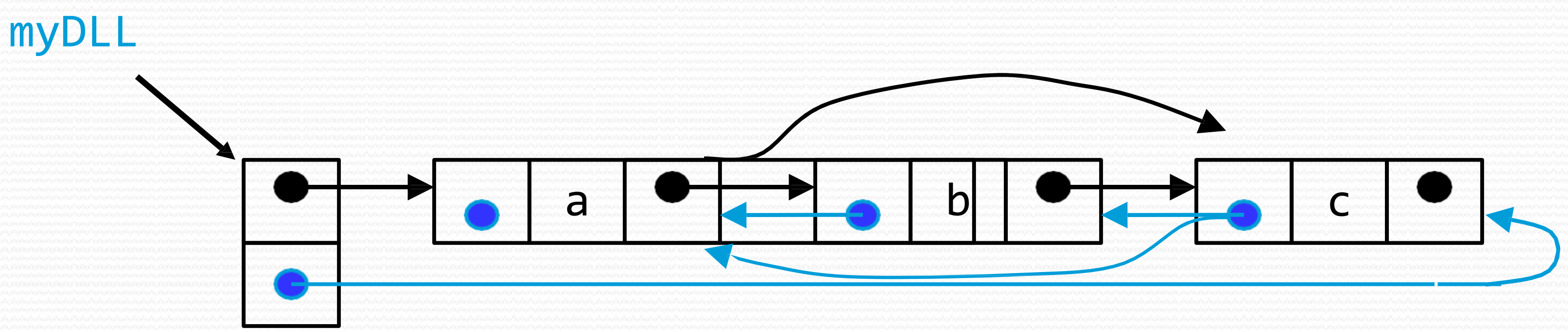


Adjusting the next and previous pointers of the nodes b/w which the new node accordingly

```
void insert_after(int c,node* p)
{
    temp=start;
    for(int i=1;i<c-1;i++)
    {
    temp=temp->next;
    }
    p->next=temp->next;
    temp->next->previous=p;
    temp->next=p;
    p->previous=temp;
    cout<<"\nInserted successfully";
}
```

Deleting a node

- Node deletion from a DLL involves changing *two* links
- In this example, we will delete node b



- We don't have to do anything about the links in node b
- Garbage collection will take care of deleted nodes
- Deletion of the first node or the last node is a special case

```
void del_at(int c)
{
    node*s=start;
     {
    for(int i=1;i<c-1;i++)
    {
     s=s->next;
    }
    node* p=s->next;
    s->next=p->next;
    p->next->previous=s;
    delete p;
    cout<<"\nNode number "<<c<<" deleted successfully";
     }
   }
}
```

APPLICATIONS OF LINKED LIST

1.Applications that have an MRU list (a linked list of file names)

2.The cache in your browser that allows you to hit the BACK button (a linked list of URLs)

3.Undo functionality in Photoshop or Word (a linked list of state)

4.A stack, hash table, and binary tree can be implemented using a doubly linked list.

Polynomials

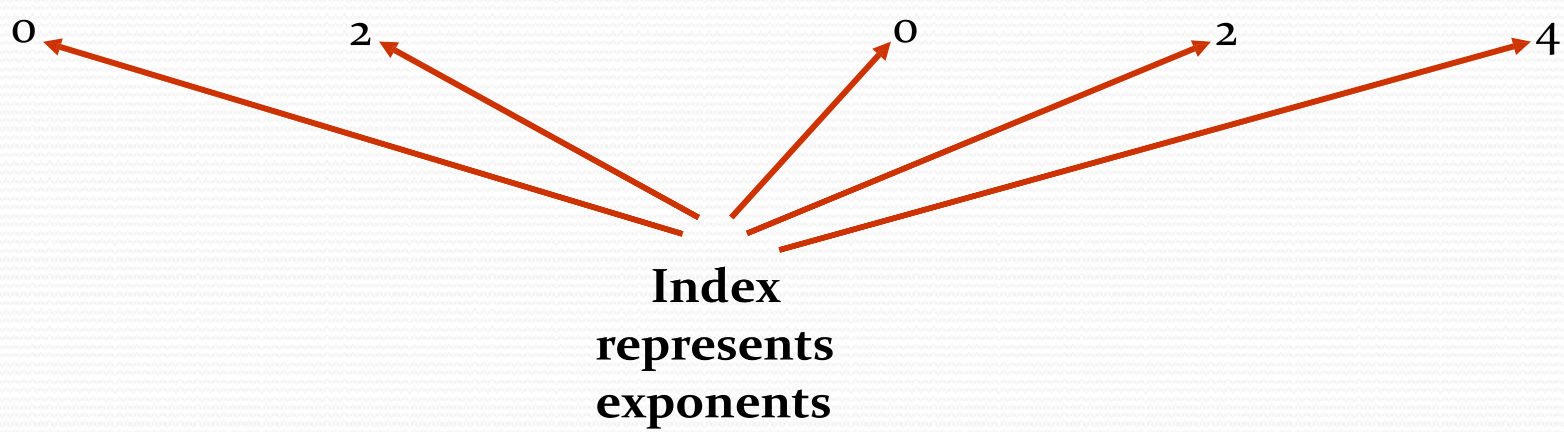
- Array Implementation:
- $p1(x) = 8x^3 + 3x^2 + 2x + 6$
- $p2(x) = 23x^4 + 18x - 3$

p1(x)

6	2	3	8

p2(x)

-3	18	0	0	23



- This is why arrays aren't good to represent polynomials:

- $p3(x) = 16x^{21} - 3x^{5} + 2x + 6$

6	2	0	0	-3	0	…………	0	16

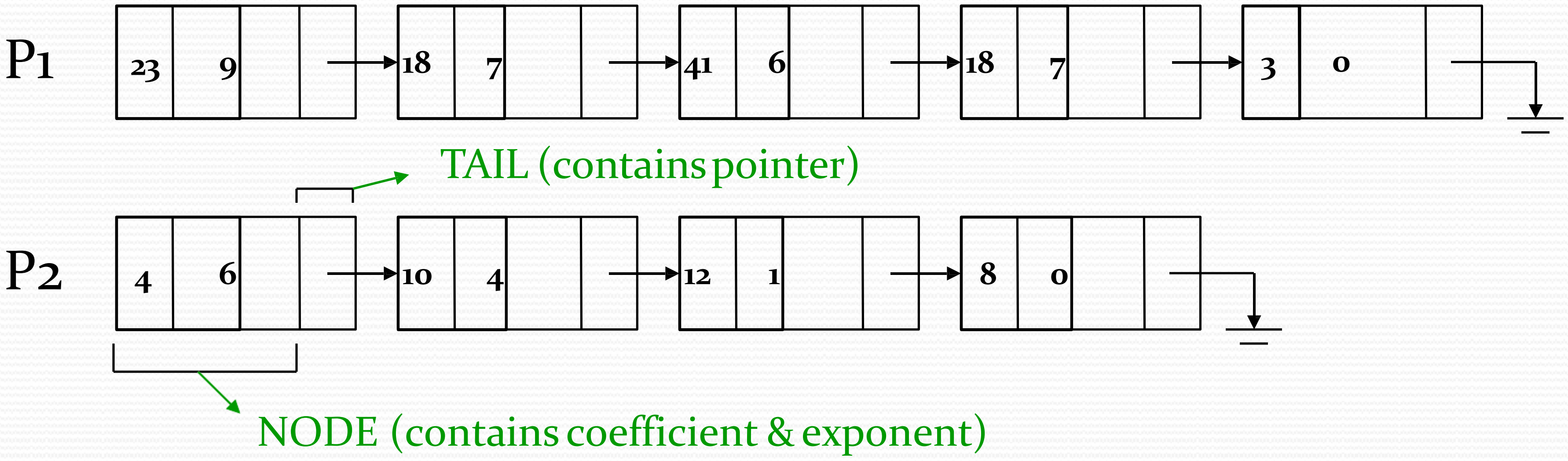
<u>WASTE OF SPACE!</u>

- Advantages of using an Array:
  - only good for non-sparse polynomials.
  - ease of storage and retrieval.
- Disadvantages of using an Array:
  - have to allocate array size ahead of time.
  - huge array size required for sparse polynomials. Waste of space and runtime.

Polynomial Representation

- Linked list Implementation:

- $p1(x) = 23x^9 + 18x^7 + 41x^6 + 163x^4 + 3$
- $p2(x) = 4x^6 + 10x^4 + 12x + 8$



- Advantages of using a Linked list:
  - save space (don’t have to worry about sparse polynomials) and easy to maintain
  - don’t need to allocate list size and can declare nodes (terms) only as needed
- Disadvantages of using a Linked list :
  - can’t go backwards through the list
  - can’t jump to the beginning of the list from the end.

Polynomials

$$A(x) = a_{m-1}x^{e_{m-1}} + a_{m-2}x^{e_{m-2}} + \ldots + a_0 x^{e_0}$$

Representation

```
struct polynode {
      int coef;
      int exp;
      struct polynode * next;
  };
```

typedef struct polynode *polyptr;

coef	exp	next

•Adding polynomials using a Linked list representation: (storing the result in p3)

To do this, we have to break the process down to cases:

- Case 1: exponent of p1 > exponent of p2
- Copy node of p1 to end of p3.

[go to next node]

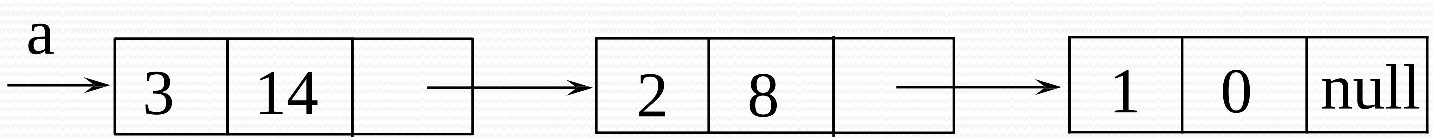
- Case 2: exponent of p1 < exponent of p2
- Copy node of p2 to end of p3.

[go to next node]

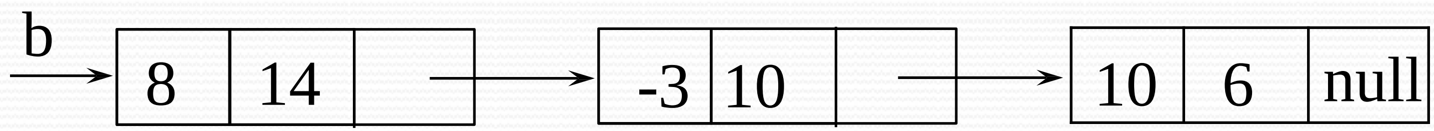
- Case 3: exponent of p1 = exponent of p2
  - Create a new node in p3 with the same exponent and with the sum of the coefficients of p1 and p2.

Example

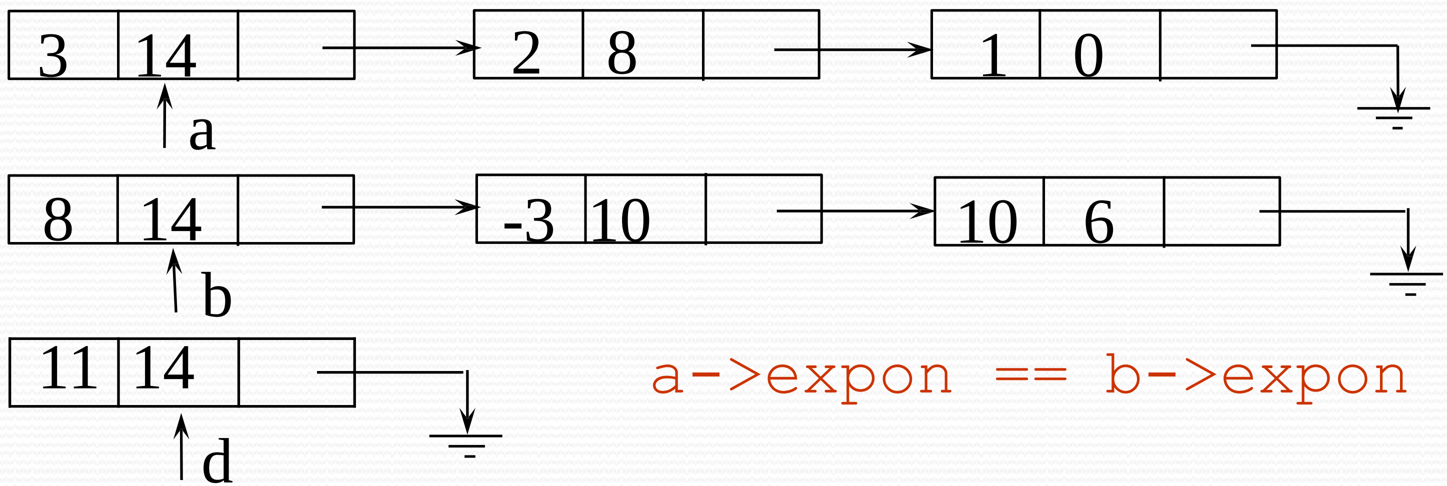
$$a = 3x^{14} + 2x^{8} + 1$$

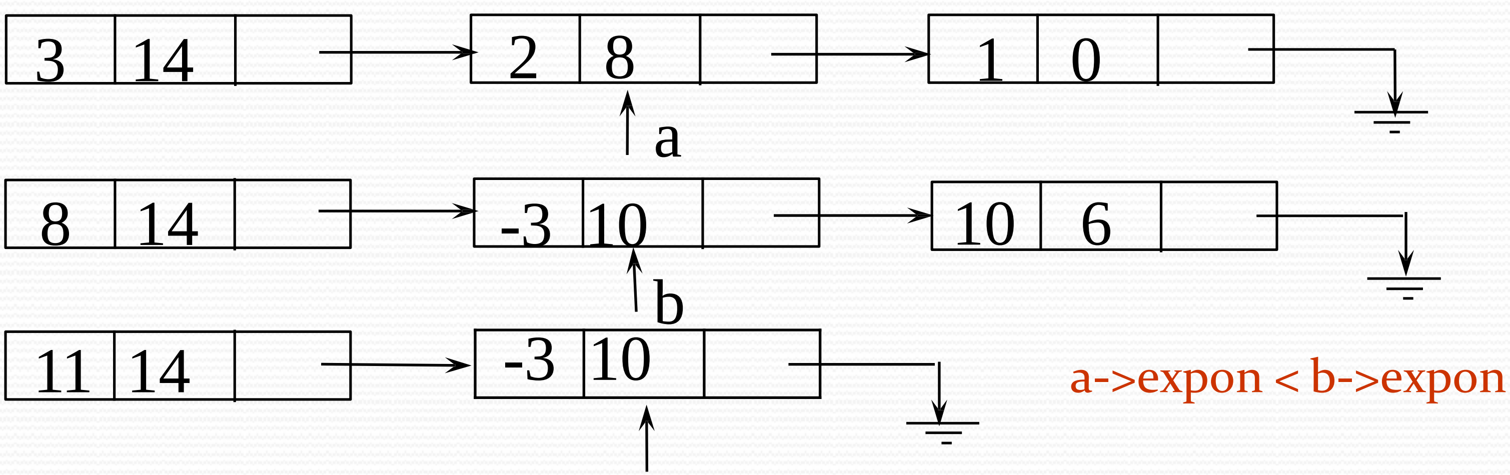


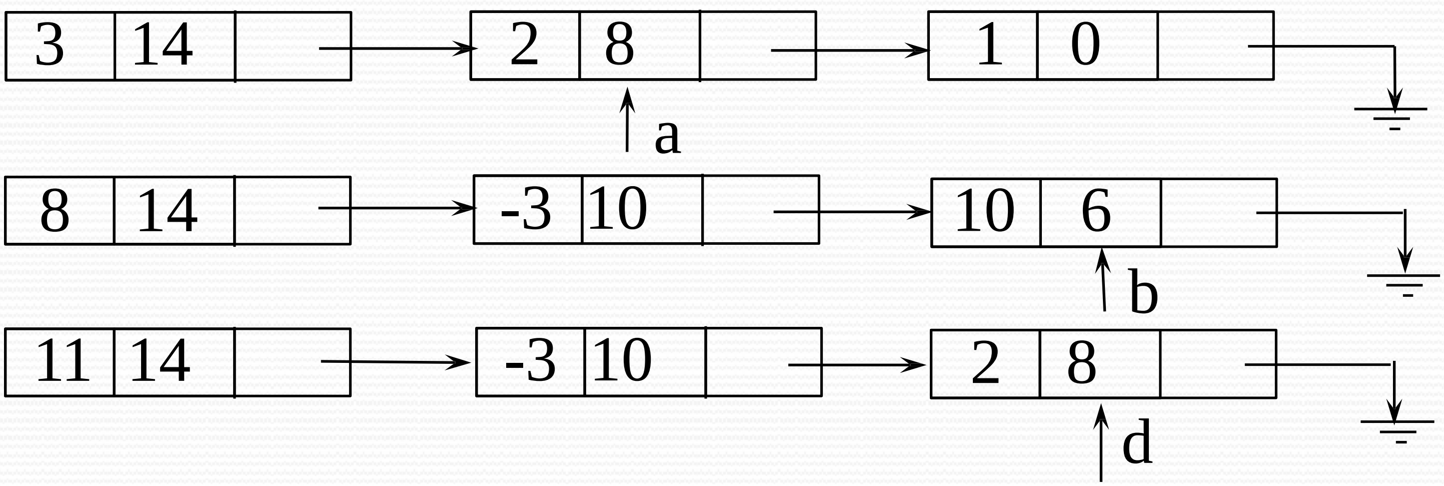
$$b = 8x^{14} - 3x^{10} + 10x^{6}$$



Adding Polynomials







a->expon > b->expon

THANK YOU