CSE 230: Data Structures

Lecture 6:Linked Lists

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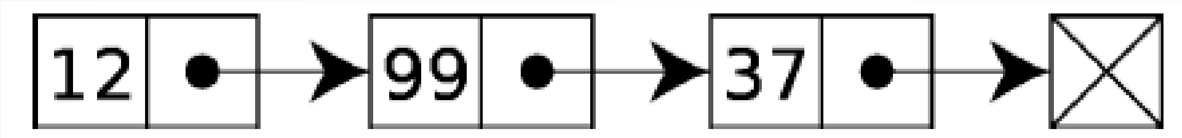
The concept

- Currently we have seen array based implementations
- Limitations of Arrays
  - The size is bounded
  - Results in too many resize operations or wastage of memory
- Solution
  - Dynamically allocate and deallocate memory as and when data is added and removed

Dynamically Allocating Elements

- Allocate elements one at a time
  - Each element keeps track of next element
- Results in a linked list of elements
  - Elements track next element with a pointer
  - elements can easily be inserted or removed without reallocation or reorganization of the entire structure

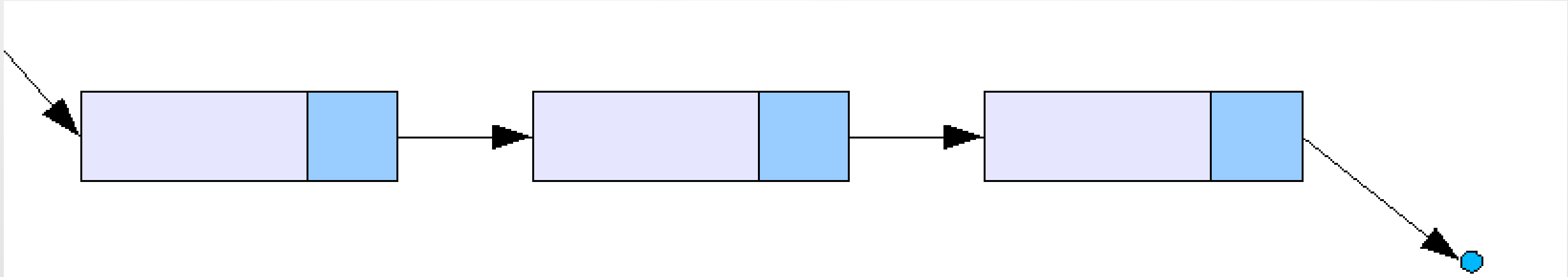


Linked Lists

- Developed in 1955-56 by Allen Newell, Cliff Shaw and Herbert A. Simon at RAND Corporation as the primary data structure for their Information Processing Language (IPL)
- Must have the following
  - Way to indicate end of list
    - NULL pointer
  - Indication for the front of the list
    - Head Node
  - Pointer to next element

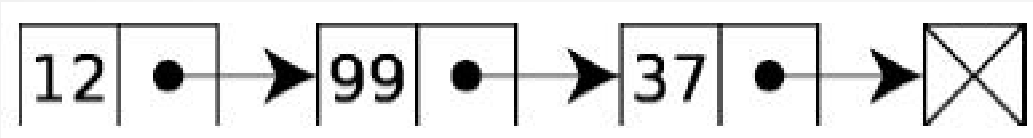
Linked Lists: Basic Concepts

- Each record of linked list is an element or a node
- Each node contains
  - Data member which holds the value
  - Pointer “next” to the next node in the list
  - Head of a list is the first node
  - Tail is the last node
- Allows for insertion and deletion at any point in the list without having to change the structure
- Does not allow for easy access of elements (must traverse to find an elt)

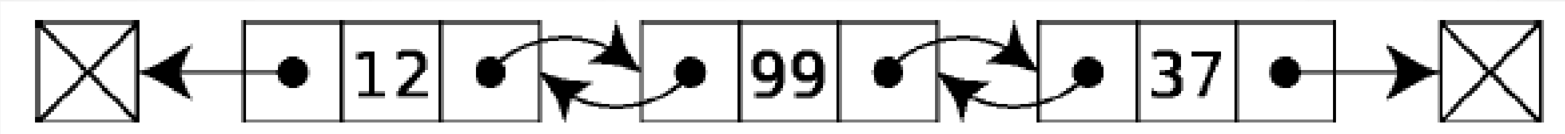


Linked Lists: Types

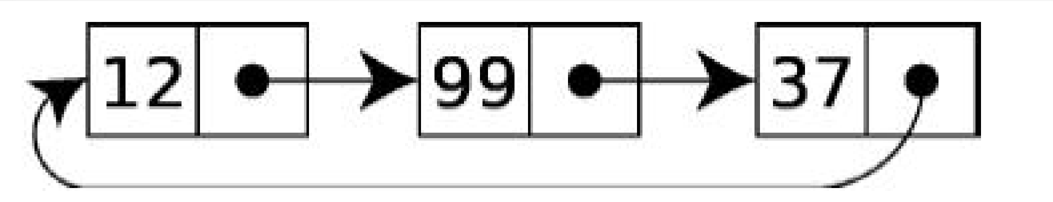
- Singly linked list



- Doubly linked list

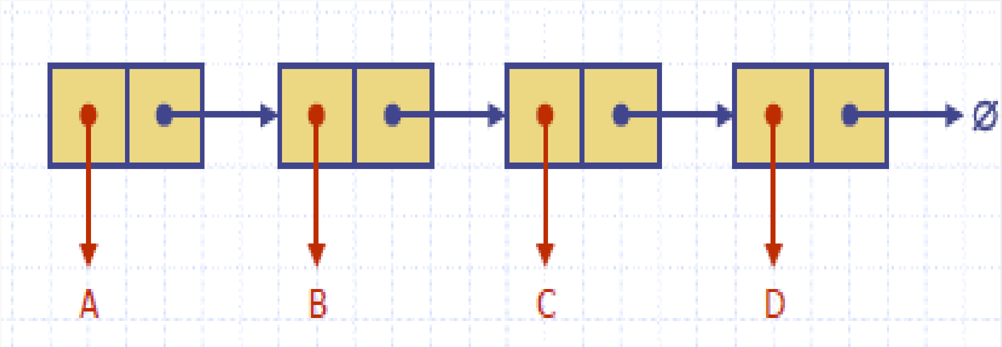


- Circular linked list



Singly Linked Lists

- Keeps elements in order
  - Uses a chain of next pointers
  - Does not have fixed size, proportional to number of elements
- Node
  - Element value
  - Pointer to next node
- Head Pointer
  - A pointer to the header is maintained by the class



Linked List in Java

- public interface ISLL<E>{

```
int size();
boolean isEmpty();
E first();
E last();
void addFirst(E e);
void addLast(E e);
E removeFirst();
E removeLast();
void printList();
```

}

Basic Linked List Definition

- public class SinglyLinkedList<E> implements ISSL<E>{

```
private static class Node<E>{
    private E element // The data being stored in the node
    private Node next // A reference to the next node, null for last node, of the type Node
    public Node (E e, Node<E> n){
        element = e;
        next = n; }
    public E getElement() { return element;}
    public Node<E> getNext() {return next; }
    public void setNext(Node<E> n)  {next = n;}
}
```

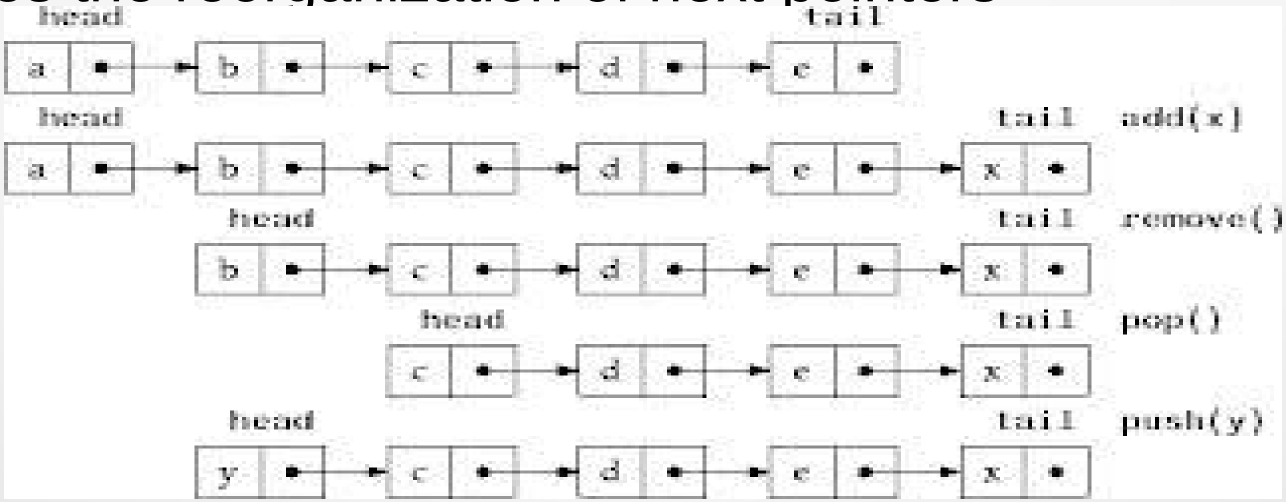
Definition contd

- public class SinglyLinkedList<E>{

```
    //nested node class goes here
    private Node<E> head = null;
    private int size =0;
    public SinglyLinkedList() {..}
    public int size() { return size;}
    public boolean isEmpty() { return size== 0;}
    public E first(){....}
        .....
}
```

Insertion and Deletion

- Insertion can be at head or tail
  - Create new node, and make new node point to head, and make it the new head
  - If using tail pointer, point next of tail to new node, and next of new node to null
- Deletion
  - Requires the reorganization of next pointers



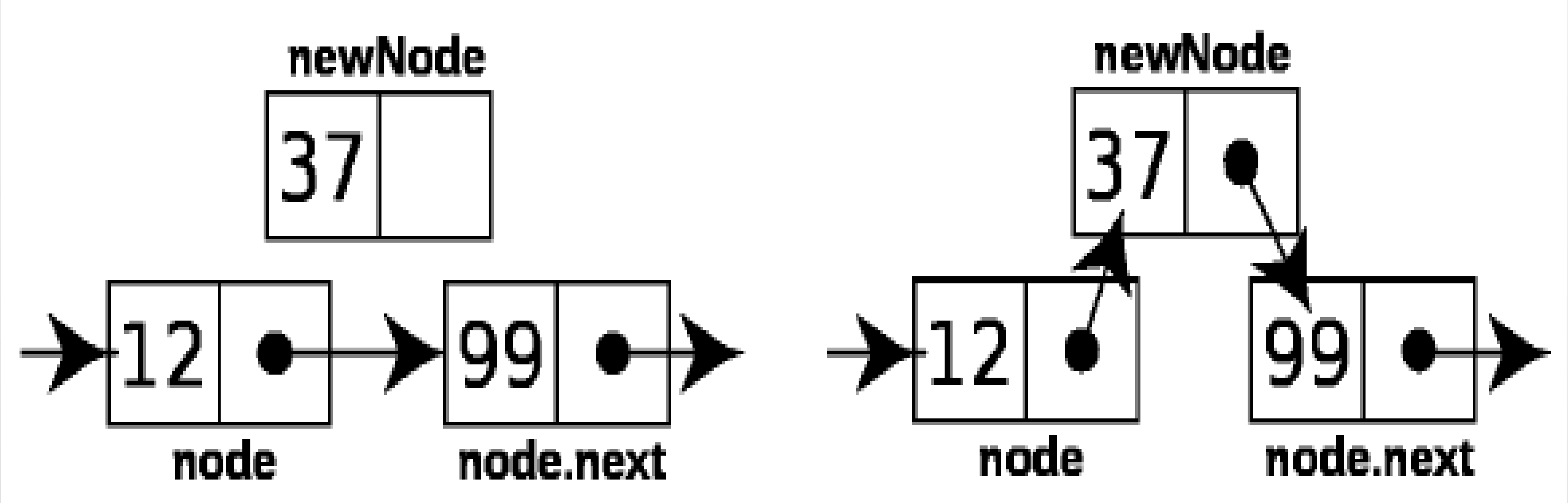
Src: opendatastructures.org

List ADT: Functions

- **Algorithm** insertAfter(Node node, Node newNode) // insert newNode after node

    newNode.next ← node.next

    node.next ← newNode



List ADT Functions:

- **Algorithm** insertFirst(List list, Node newNode)

  // insert node before current first node

  newNode.next := list.firstNode

  list.firstNode := newNode

- **Algorithm** insertLast(List list, Node newNode)

  // insert node after the current tail node

  tail.next ← newNode

  newNode.next ← NULL

Java Implementation

```
public void addFirst(E e) {                    // adds element e to the front of the list
  head = new Node<>(e, head);                  // create and link a new node
  if (size == 0)
    tail = head;                               // special case: new node becomes tail also
  size++;
}
public void addLast(E e) {                     // adds element e to the end of the list
  Node<E> newest = new Node<>(e, null);        // node will eventually be the tail
  if (isEmpty())
    head = newest;                             // special case: previously empty list
  else
    tail.setNext(newest);                      // new node after existing tail
  tail = newest;                               // new node becomes the tail
  size++;
}
```

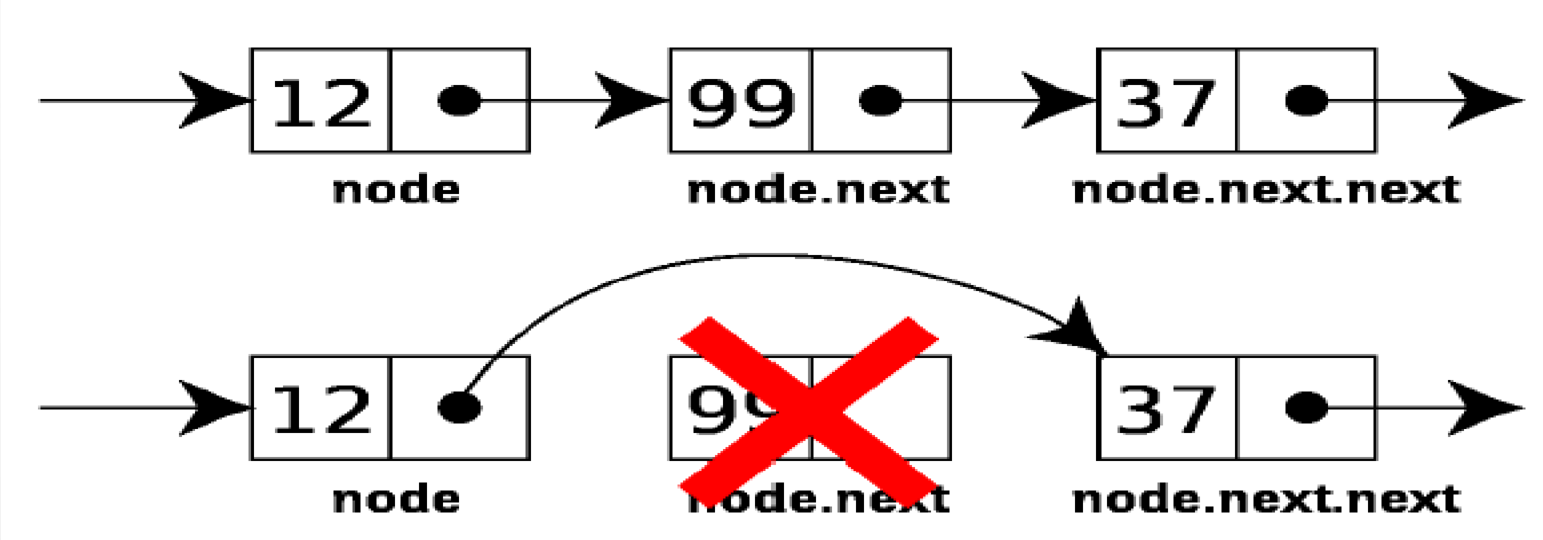
List ADT: Delete Functions

- **Algorithm** removeAfter(Node node) // remove node past this one

  obsoleteNode ← node.next

  node.next ← node.next.next

  destroy obsoleteNode



Java Function

```
public E removeFirst() {                  // removes and returns the first element
  if (isEmpty()) return null;             // nothing to remove
  E answer = head.getElement();
  head = head.getNext();                  // will become null if list had only one node
  size--;
  if (size == 0)
    tail = null;                          // special case as list is now empty
  return answer;
}
}
```

Traversing the list

- Algorithm Traverse()
  - Node ← list.firstNode
  - while node not null

    do something with node.element

    node ← node.next

Other possible list functions

- first() : return the first node of the list, error if S is empty
- last(): return last node of the list, error if S is empty
- isFirst(*p*): returns true if *p* is the first or head node
- isLast(*p*): returns true if *p* is the last node or tail
- before(*p*): returns the node preceding the node at position *p*
- *getNode(i): return the node at position i*
- after(*p*): returns the node following the node at position *p*
- size() and isEmpty() are the usual functions

List: Update Functions

- replaceElement(*p*,*e*): Replace element at node at *p* with element *e*
- swapElements(*p*,*q*): Swap the elements stored at nodes in positions *p* and *q*
- insertBefore(*p*,*e*) Insert a new element *e* into the list S before node at *p*

Complexity Analysis

- Time Complexity
  - size – O(n)
  - isEmpty – O(1)
  - first(), isFirst(), isLast()– O(1)
  - insertAfter(*p,e*), after(*p*) – O(1) (if pointer to p given)
- Space Complexity
  - O(n)

Exercises

- Give an algorithm for finding the penultimate node in a singly linked list where the last element is indicated by a null next pointer
- Give an algorithm for concatenating two singly linked lists L and M, with header nodes, into a single list L' where
  - L' contains all nodes of L in their original order followed by all nodes of M (in original order)
  - What is the running time of your algorithm if n is the number of nodes in L, and m is the number of nodes in M?

Stack: Linked List Based Implementation

- Top element is stored as the head (first node) of the linked list
- Insertion and deletion always at the front
- The stack class has the following variables
  - Node topnode //top is the head node
    - Initialized to NULL
  - sz //variable to keep track of the size of the list
    - initialized to 0

Stack ADT Functions

- **Algorithm** size()

  return sz

- **Algorithm** isEmpty()

  return (*sz* == 0)

- **Algorithm** top()

  if isEmpty() **then**

      throw a StackEmptyException

  return *topnode.element*

Stack ADT Functions

- **Algorithm** push(*o*)

  if size() = *N* **then**

  throw a StackFullException

  newNode ← *new Node(o, topnode)*

  topnode ← *newNode*

  sz++

Stack ADT Functions

- **Algorithm pop**()

  if isEmpty() **then**

  throw a StackEmptyException

  Node oldNode ← *topnode*

  topnode ← *topnode.next*

  sz--

  o ← *oldNode.element*

  delete oldNode

  return *o*

Queue: Linked List Based Implementation

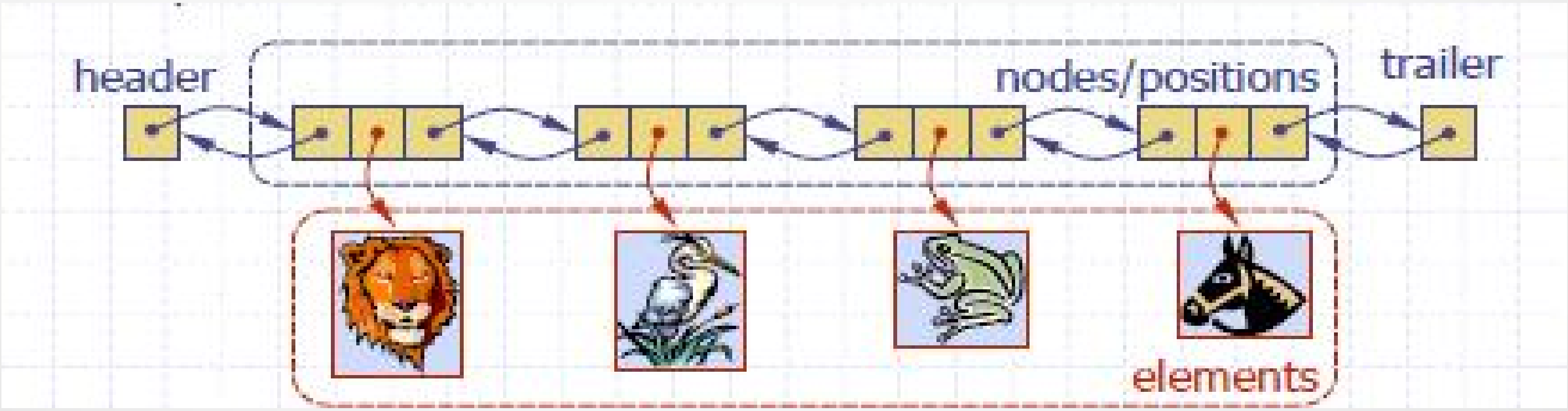
- Can be done similarly
- Here insertion is done at the tail
- Deletion is at the head

Exercises

- Design and implement an SLList method, secondLast(), that returns the second-last element of an SLList. Do this without using the member variable, n, that keeps track of the size of the list.
- Describe and implement the following List operations on an SLList
  - get(i) // get the node at position i
  - set(i,x) // set the value of node at ith position to x
  - add(i,x) // add a node with value x with position i
  - remove(i). //remove node at position i
  - Each of these operations should run in O(1 + i) time.

Doubly Linked List

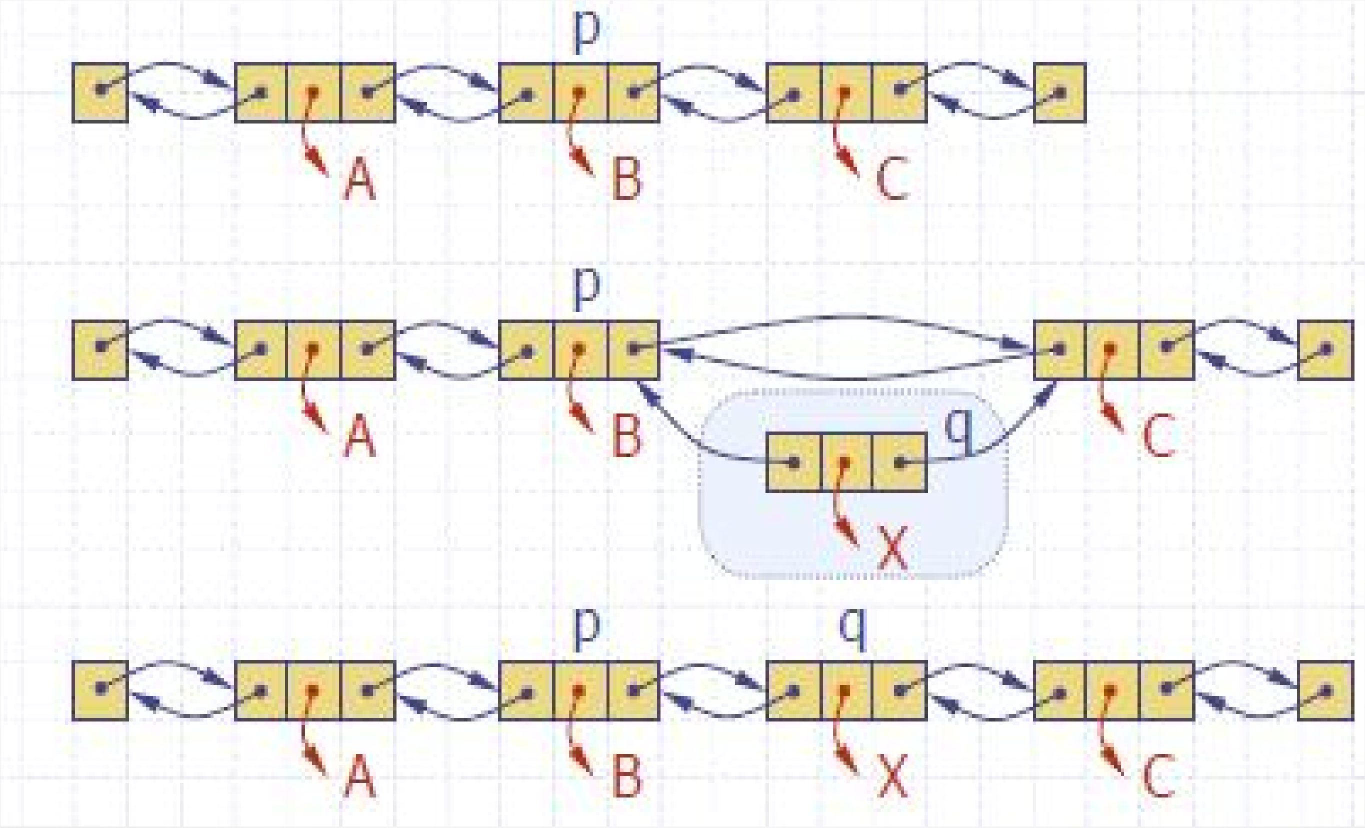
- Nodes implement the position and store the following
  - Element
  - Link to previous node
  - Link to next node
- Trailer and Header nodes



Src: Goodrich notes

Insertion: Doubly Linked List

- insertAfter(p,X)



InsertAfter

- **Algorithm** insertAfter (Node p, Value x) // insert newNode before node

  q ← new Node()

  q.value ← x

  q.next ← p.next

  q.prev ← p

  q.next.prev ← q

  q.prev.next ← q

  n++; //increment size

InsertBefore

- **Algorithm** insertBefore (Node r, Value x) // insert newNode before node

  q ← new Node()

  q.value ← x

  q.prev ← r.prev

  q.next ← r

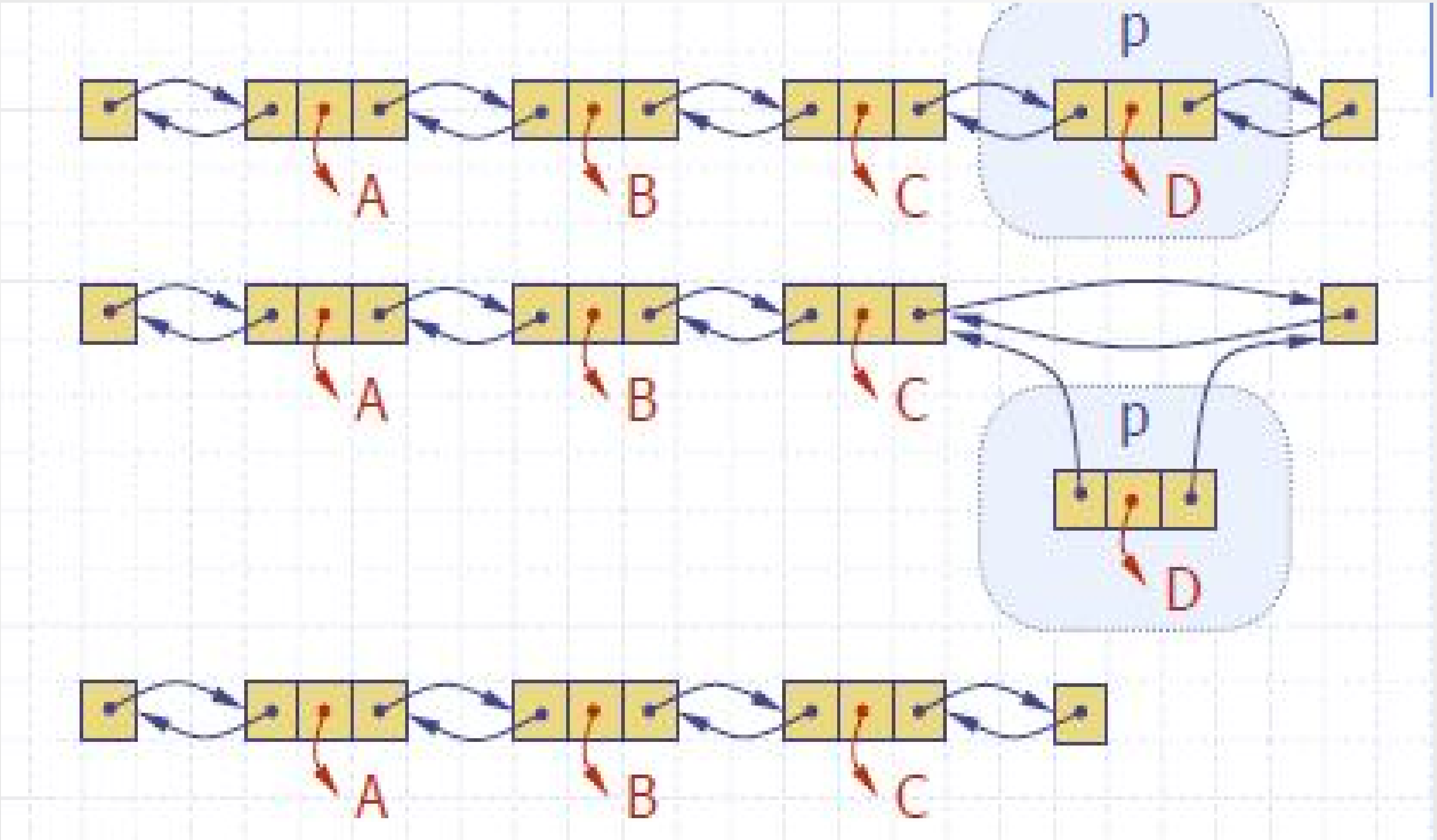
  q.next.prev ← q

  q.prev.next ← q;

  n++; //increment size

Deletion: Doubly Linked List

- remove(p)



Remove Operation

- **Algorithm** remove(Node *p*)

    p.prev.next ← *p*.next

    p.next.prev ← *p*.prev

    delete *p*

Getting a Node given a location

- **Algorithm** getNode(*p*)

```
Node tnode
if (p < n / 2)
    tnode ← head.next;
    for (i = 0; i < p; i++)
        tnode ← tnode.next
    else
        tnode ← tailnode
        for (i = n; i > p; i--)
        tnode ← tnode.prev
return (tnode)
```

Doubly Linked List vs Singly Linked List

- Doubly linked list requires more space per node
  - Elementary operations more expensive
- Allow sequent access in both directions
  - one can insert or delete a node in a constant number of operations given only that node's address
  - in a singly linked list, one must have the address of the pointer to that node or the link field in the previous node

Circular Linked List

- If in a linked list, the tail points to the head, it is a circular linked list
  - Can be for both singly or doubly linked list
- Works for arrays that are naturally circular
  - Representing points in a polygon
  - Processes to be scheduled in round robin order
- Supports access to both ends of the list without using extra pointers
- Can traverse the full list from any node

Exercises

- Give an algorithm to merge two doubly linked lists L and M into one list. What is the running time of your algorithm.
- Give a pseudocode of an algorithm to swap two nodes x, and y in a singly linked list given pointers only to x and y.
  - Do the same for the case of a doubly linked list
- Describe in pseudocode a linear-time algorithm for reversing a singly linked list L, so that the ordering of the nodes becomes exactly opposite of what it was before.