03. Special Linked Structures

- *Introduction*
- *Linked Lists*
- *Doubly Linked Lists*
- *Circular Linked Lists*

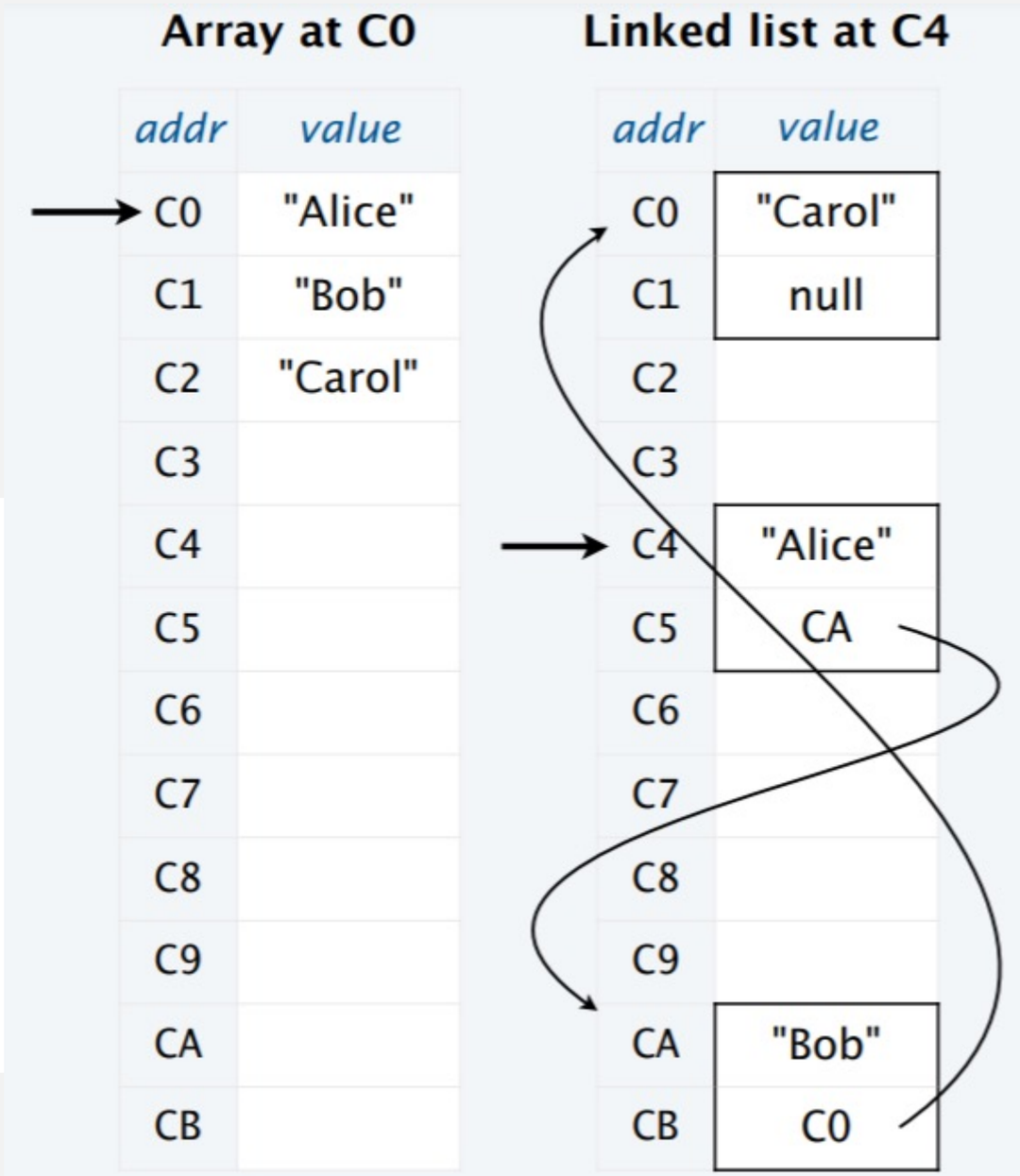
Sequential and Linked Data Structures

Sequential data structure

- Put objects next to one another.
- Machine: consecutive memory cells.
- Java: array of objects.
- Fixed size, arbitrary access. ⟵ *i*th element

Linked data structure

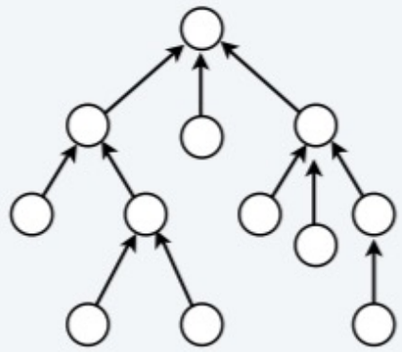
- Associate with each object a link to another one.
- Machine: link is memory address of next object.
- Java: link is reference to next object.
- Variable size, sequential access. ⟵ *next* element
- Overlooked by novice programmers.
- Flexible, widely used method for organizing data.



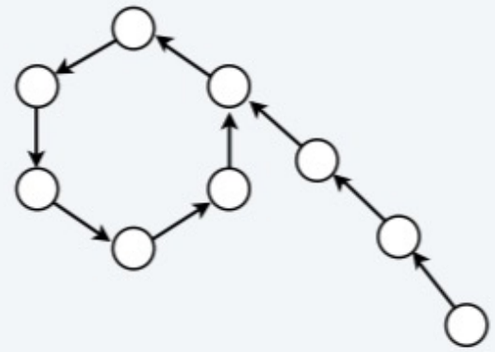
Linked Data Structures

Linked list (this lecture)

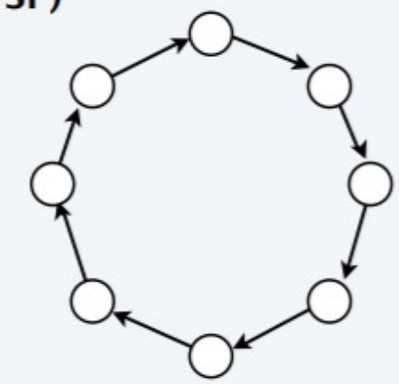
Tree



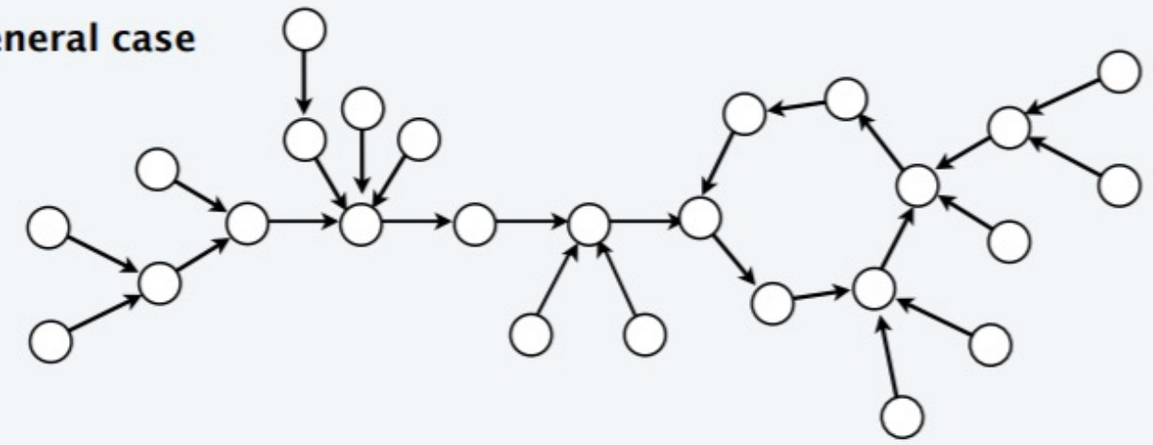
Rho



Circular list (TSP)



General case



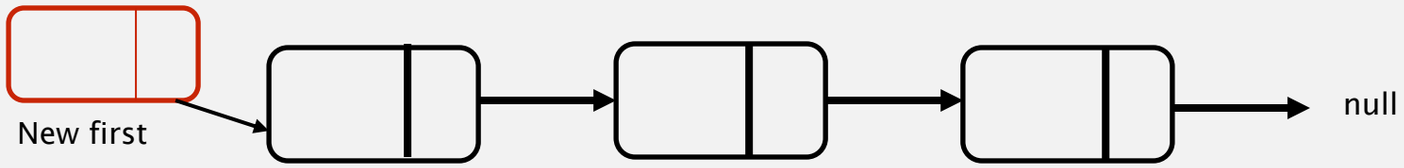
Multiply linked structures: many more possibilities!

From the point of view of a particular object, all of these structures look the same.

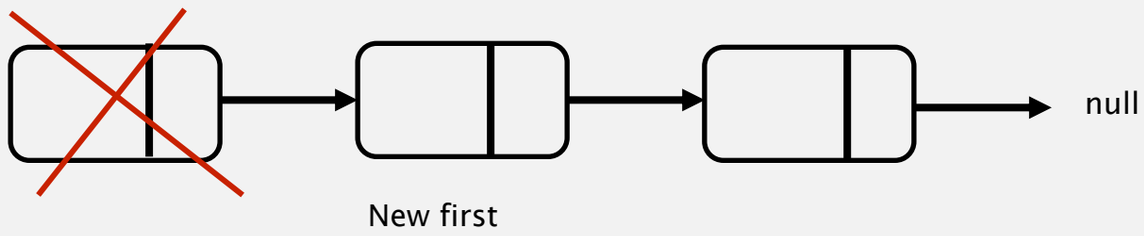
List Processing Code

Standard operations for processing data structured as a singly-linked list

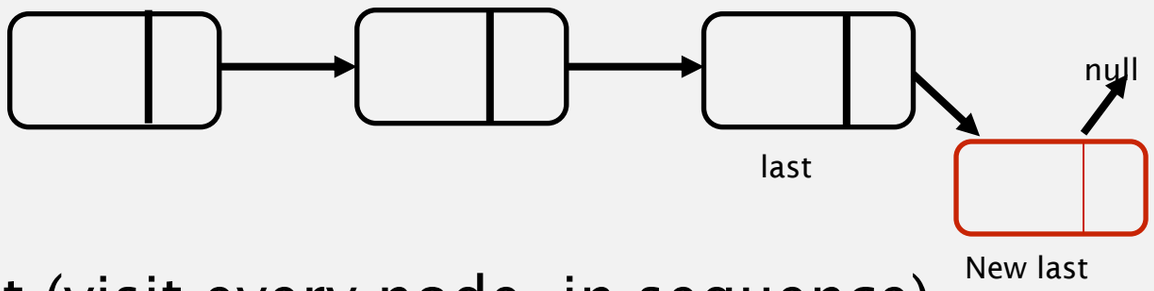
- Add a node at the beginning of the list



- Remove and return the node at the beginning

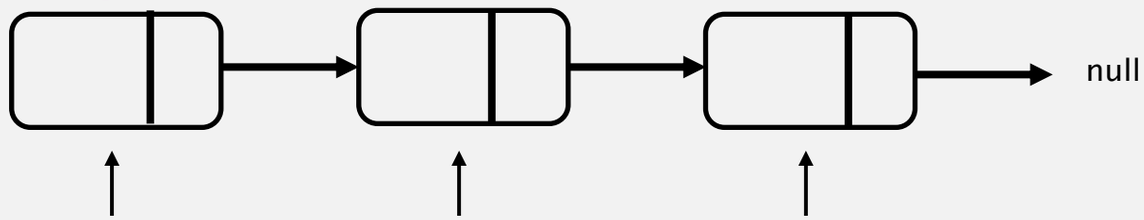


- Add a node at the end (requires a reference to the last node)



- Traverse the list (visit every node, in sequence).

```
in one direction only
```



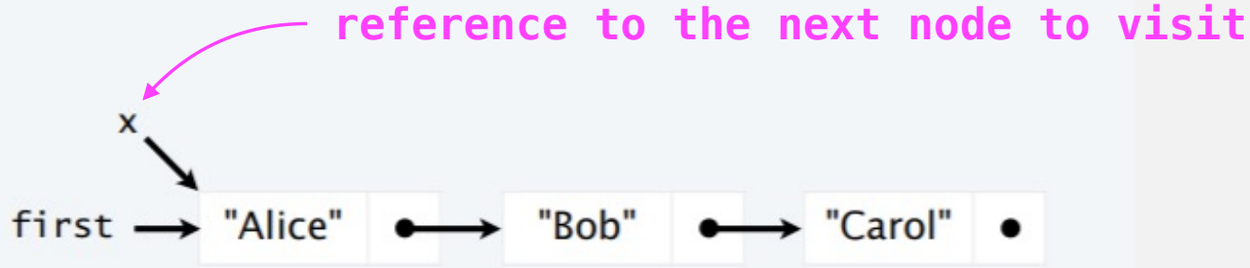
List processing code – Traverse a List

Goal. Visit every node on a linked list `first`.

priming

```
Node x = first;
while (x != null)
{
   StdOut.println(x.item);
   x = x.next;
}
```

update the reference for the next iteration



StdOut

```
Alice
Bob
Carol
```

Pop quiz1 on Linked Lists

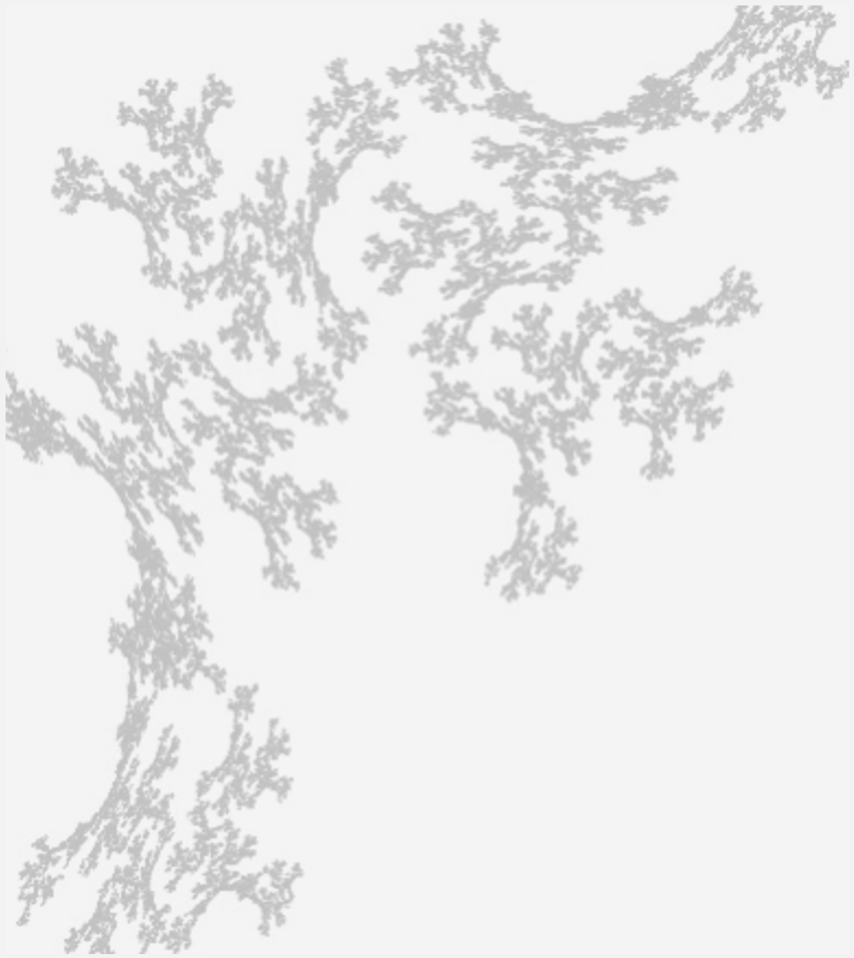
Q. What is the effect of the following code (not-so-easy question)?

```
...
Node list = null;
while (!StdIn.isEmpty())
{
   Node old = list;
   list = new Node();
   list.item = StdIn.readString();
   list.next = old;
}
for (Node t = list; t != null; t = t.next)
   StdOut.println(t.item);
...
```

Pop quiz 2 on Linked Lists

Q. What is the effect of the following code (not-so-easy question)?

```
...
Node list = new Node();
list.item = StdIn.readString();
Node last = list;
while (!StdIn.isEmpty())
{
   last.next = new Node();
   last = last.next;
   last.item = StdIn.readString();
}
...
```



Special linked Structures

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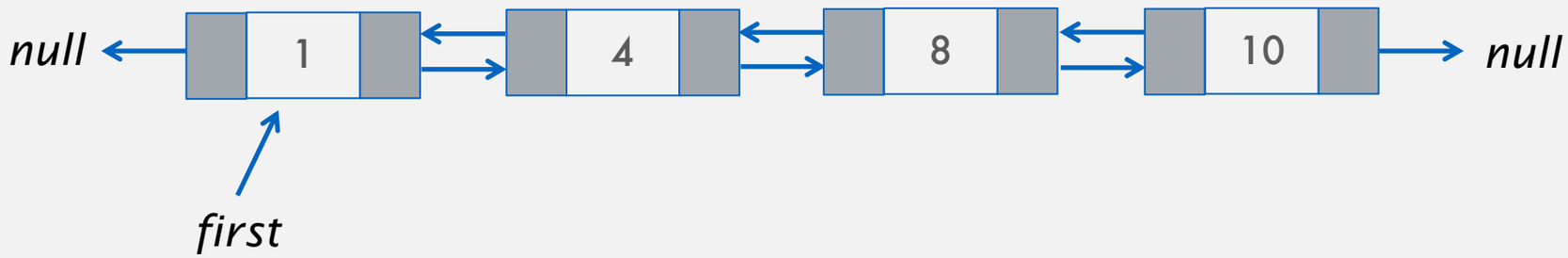
- *Doubly Linked Lists*
- *Circular Linked Lists*

Doubly Linked Lists

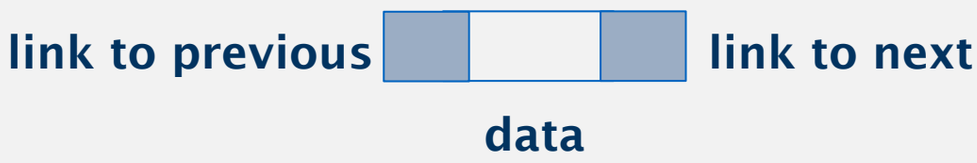
A linked list where every node refers to its previous and next nodes

traversing is bi-directional



Each node has three parts:

- a data part
- a link to the previous node
- a link to the next node




```
class DoublyLinkedList <T> {
    Node first;
    int n;
}
```

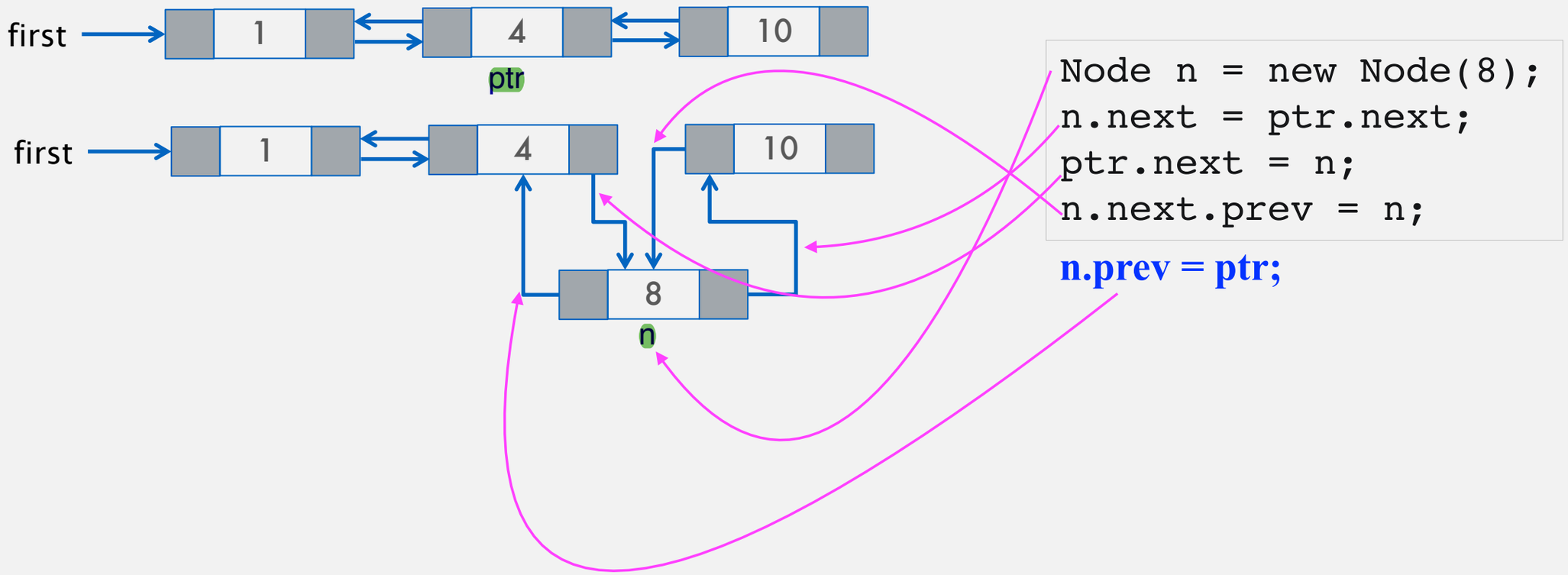
```
class Node <T> {
    T data;
    Node prev;
    Node next;
}
```

additional ref.

Implementation of a Doubly Linked List

Insert after a target

Create the new node 8 and insert it after 4



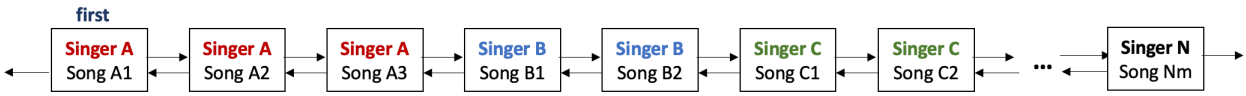
Running time? O(1)

for the insertion operation ONLY, or insertion to front

Insertion at target location needs to find the target location first, worst case O(n).

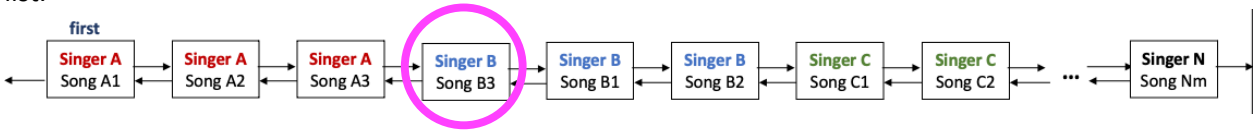
Problem 1 – Doubly Linked List (20 points)

A music library is kept in a doubly linked list, see the following `MusicLibrary` class. The library organizes all the songs that belong to the same singer in consecutive nodes. On the example below all singer A's songs are in consecutive nodes, so are the songs for singer B and singer C's songs.




```
public class MusicLibrary {

    private Node first;  // first node of the list
    int size;            // number of items on the list

    public class Song {
        String singer;   // singer/songwriter name
        String name;     // song's title
        String file;     // location of the song file
    }

    private class Node {
        Song item; // data (the song)
        Node prev; // link to the previous node on the list
        Node next; // link to the next node on the list
    }

    public void addSong (Song s) {
        // WRITE YOUR CODE HERE
    }
}
```

Write the method addSong(Song s) that inserts a song into the Music Library list as the first song for its singer. For example, if song B3 for singer B is inserted into the list it will be inserted before any of singer B's songs (see the image below). If the current list has no songs from the singer, add to the end of the list.



update pointers

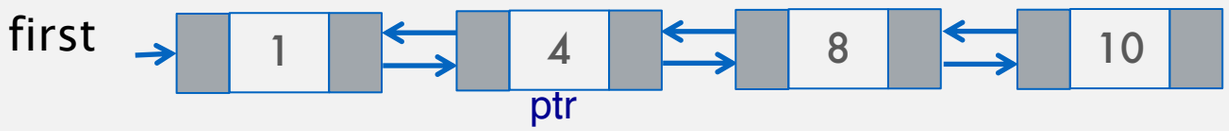
SOLUTION

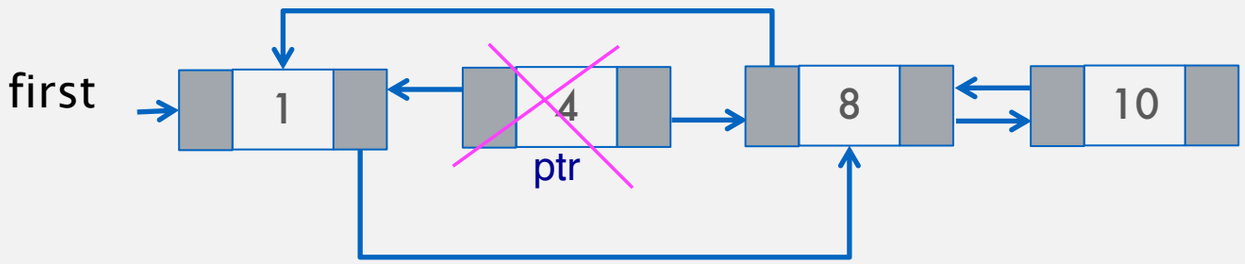
```
public void addSong (Song s) {

    // WRITE YOUR CODE HERE

    Node n = new Node();
    n.item = s;

    // 1. list could be empty [2 points]
    if ( first == null ) { // if ( size == 0 ) is also correct
        first = n;         // 2 points for updating first when the list is empty
        size += 1;
        return;
    }

    // 2. Find where to add, before the first song of s.singer [12 points]
    Node previous = null;
    for ( Node ptr = first; ptr != null; ptr = ptr.next ) { // loop or recursion to traverse the list [2 points]
        if ( ptr.item.singer.equals(s.singer) ) {    // compare to find the first s.singer's song [2 points]
            // add before ptr
            n.prev = ptr.prev; // point to node before ptr (last song of previous singer) [2 points]
            n.next = ptr;      // point to ptr (current first node of s.singer) [2 points]
            n.prev.next = n;   // update previous (last song of previous singer) to point to n [2 points]
            n.next.prev = n;   // update ptr (current first node of s.singer) to point to n [2 points]
            size += 1;
            return;
        }
        previous = ptr;
    }

    // 3. There are no songs of s.singer, s is the first song to be added, add at the end
    // add after last node, prev points to last node [6 points]
    n.prev = previous; // point to node before ptr (last song of previous singer) [3 points]
    n.next = null;     // this line is not needed
    n.prev.next = n;   // update previous (last song of previous singer) to point to n [3 points]
    size +=1 ;
}
```

Implementation of a Doubly Linked List

Remove a target

Delete node containing 4






```
ptr.prev.next = ptr.next;
ptr.next.prev = ptr.prev;
```

Running time?

- Best case if target is the first node: O(1)
- Worst case if target is the last node: O(n)

Applications of Doubly Linked Lists

LO 3.4, 3.6

- A doubly linked might be suitable for many applications where it is important to be able to navigate the linked structure in any direction (forward or backward)

- An application is to maintain the history of web pages visited where both backward and forward navigation of the history is possible.

- In some applications it can be used to maintain most and least recently used memory cache.

- One can design a music player with a next and previous buttons to maintain the history of the playlist, both forward and backward.

Advantages and Disadvantages of Doubly Linked Lists

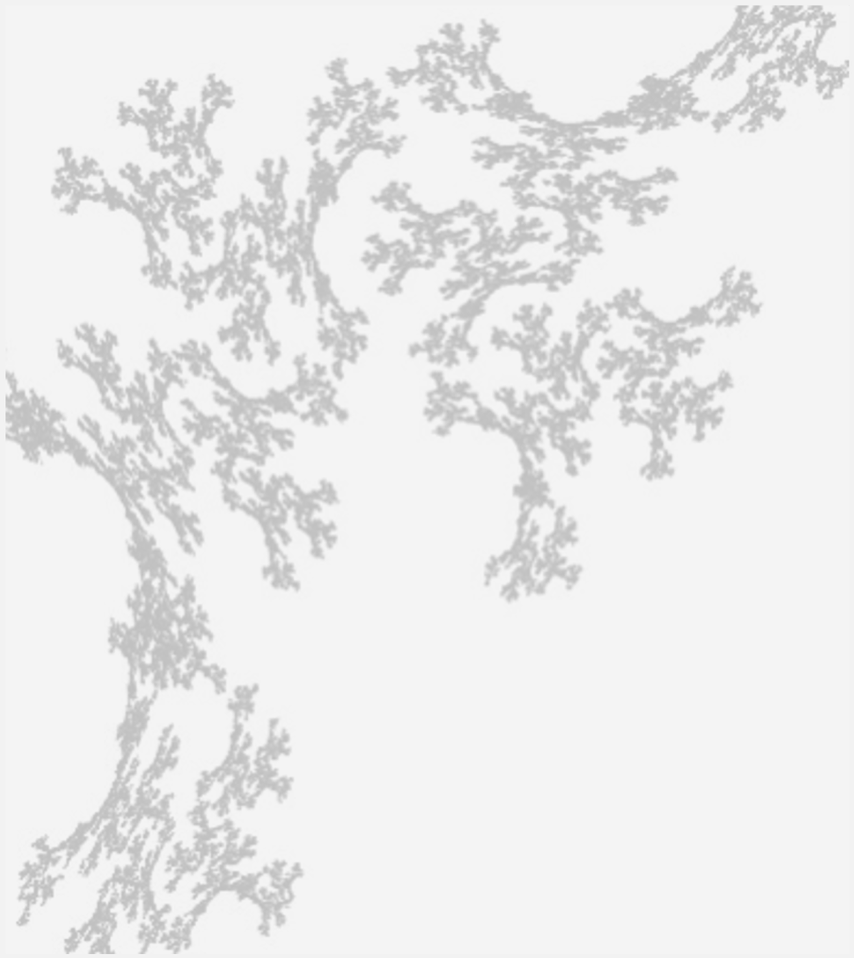
LO 3.4

Disadvantages

- Each node requires extra 8 bytes of memory for previous reference
- It is harder to implement methods as operations such as inserting a node to the middle requires 4 statements

Advantages

- More versatile than singly linked list as one can traverse in both directions.
- When implementing a dynamic application, reference to mostRecentlyAccessednode can be saved in order to move forward or backward.



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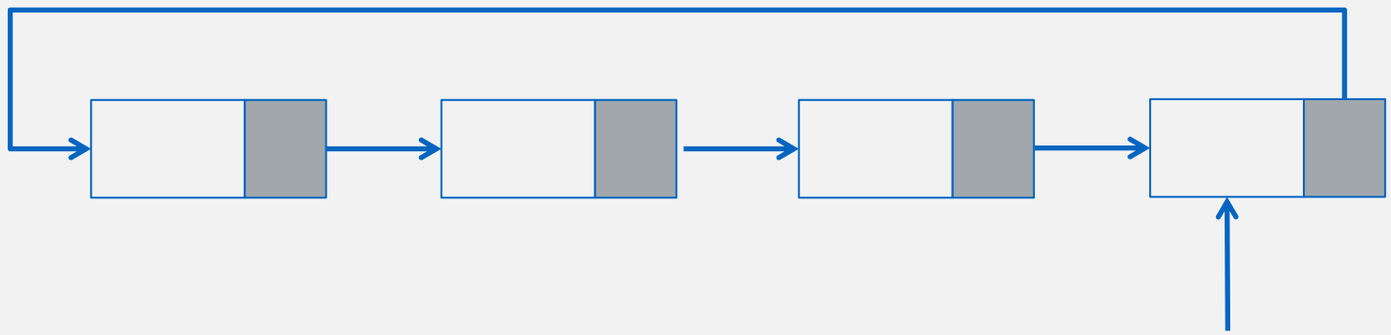
Circular Linked Lists

LO 3.1

A circular link list is a special form of a singly linked list where all nodes are in a continuous cycle. There is no use of null in a circular link list to indicate the end of the list.



By keeping a pointer to the last entry we have access to the *first* and *last* entry in constant time.
last: last
first: last.next

```
class CircularLinkedList <T> {
    Node last;
    int n;
}
```

Circular Linked lists have the property that the last node refers back to the first node: last.next is the reference to the first node

Advantages of Circular Linked Lists

LO 3.4

A circular linked list can be traversed beginning at any node in the list.

A circular linked list can be used to implement a data structure such as a queue where two references front, and back are needed. However, we note that back.next = front

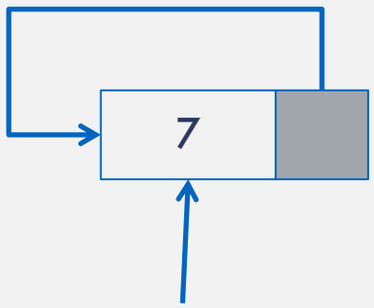
A circular linked list can also be singly or doubly.

Implementation of a circular Linked List

Add to front: add an element to the front of the list

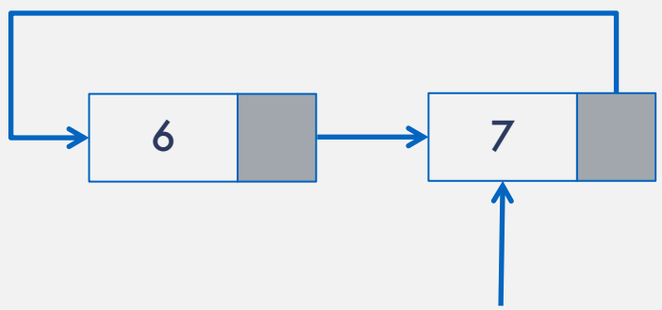
Two cases:

1. List is empty




```
Node n = new Node();
n.data = 7;
n.next = n;
last = n;
```

2. List is not empty




```
Node n = new Node();
n.data = 6;
n.next = last.next;
last.next = n;
```

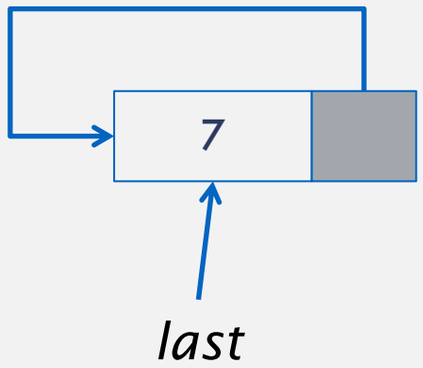
Running time: O(1)

Implementation of a circular Linked List

Remove front: deletes the first element of the list

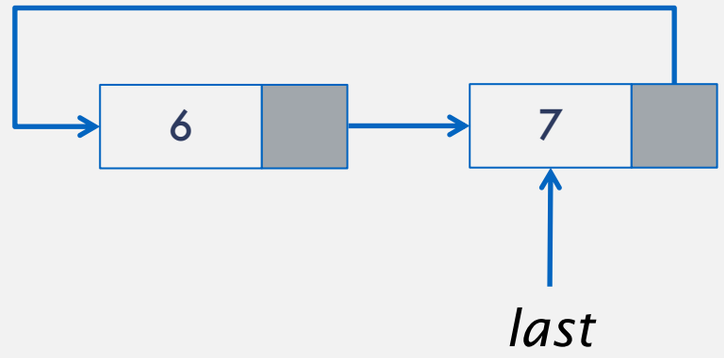
Three cases:

1. List is empty
2. One element

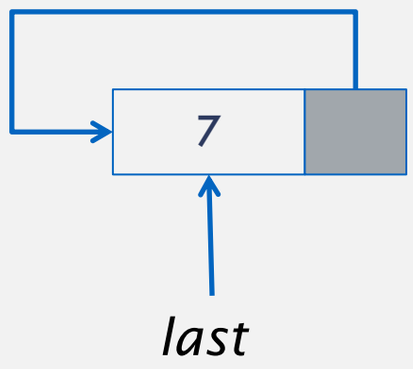



```
last = null;
```

3. More than one element




```
last.next = last.next.next;
```

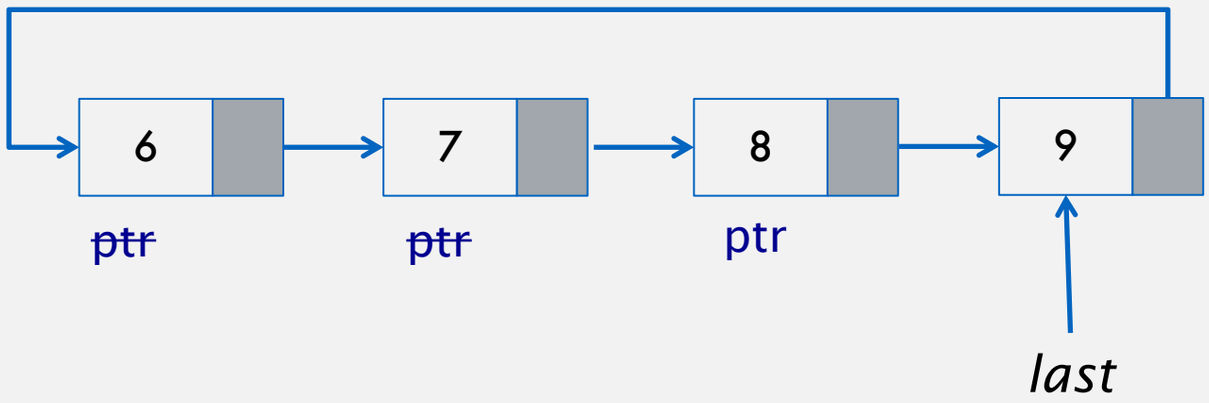


Running time: O(1)

Implementation of a circular Linked List

To search in a CLL: say target is 8

1. Start a pointer at the front
2. Advance pointer until target is found or the beginning of the list is reached again.




```
Node ptr = last.next;  Front
do{
    if (ptr.data == target) {
     break;
    }
    ptr = ptr.next;  next iteration
} while (ptr != last.next);
```

Front

What is the running time?

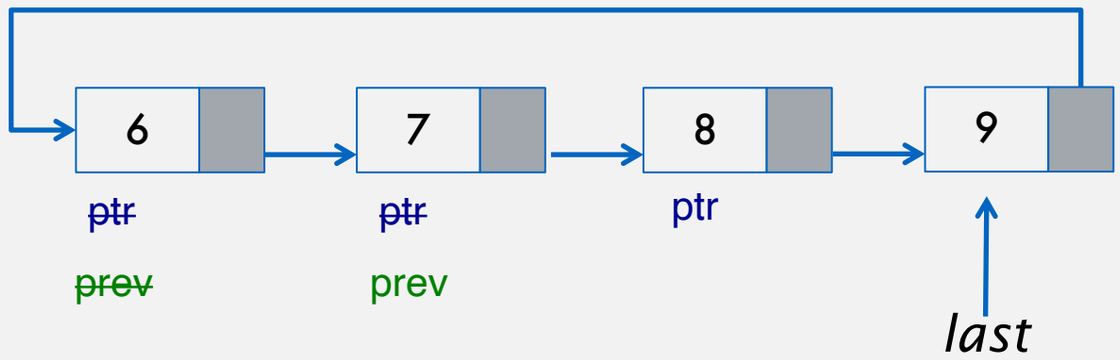
Worst: O(n)

Best: O(1)

Implementation of a circular Linked List

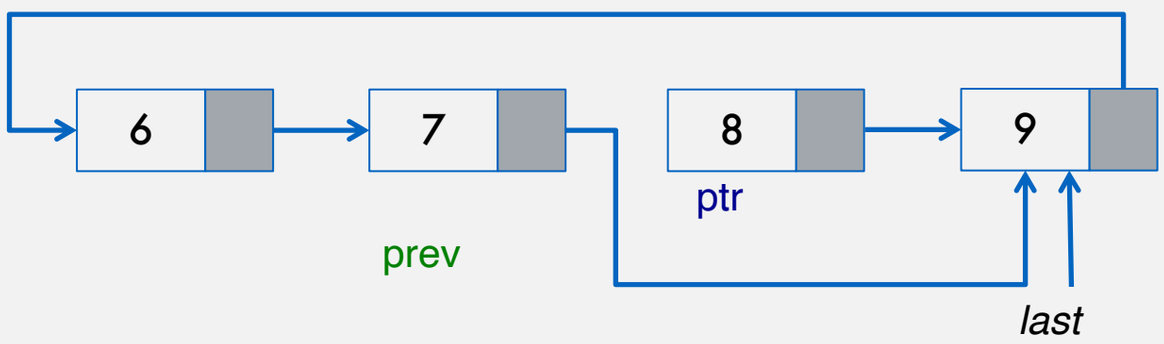
Delete target: removes the node with the target value

1. Find target




```
Node ptr = last.next;   Front
Node prev = last;
do{
    if (ptr.data == target) {
     break;
    }
    prev = ptr; keep this to update the ref.
    ptr = ptr.next;
} while (ptr != last.next);
```

2. Delete target




```
prev.next = ptr.next;
```

delete the node by changing the ref. to next node

What is the running time?
- Worst if removing the last node: O(n)
- Best if removing the first node: O(1)

Three cases:
1. target not found (ptr == last.next)
2. target is last int the list (ptr == last)
3. target is found and is not the last in the list

Applications of Circular Linked Lists

LO 3.4, 3.5

- A circular linked list can be used to implement a queue, where only one reference is needed to implement enqueue or deque operations

- A circular linked list can be used to allocate a shared resource to multiple applications where each application is given some fixed amount of time and the operations can be continued until all applications complete their tasks

- A circular linked list can be used in a multi player game, where each player is given a chance in sequence, and first player is given a chance again in the second round once the last player is done in the first round.

Advantages and Disadvantages of Circular Linked Lists

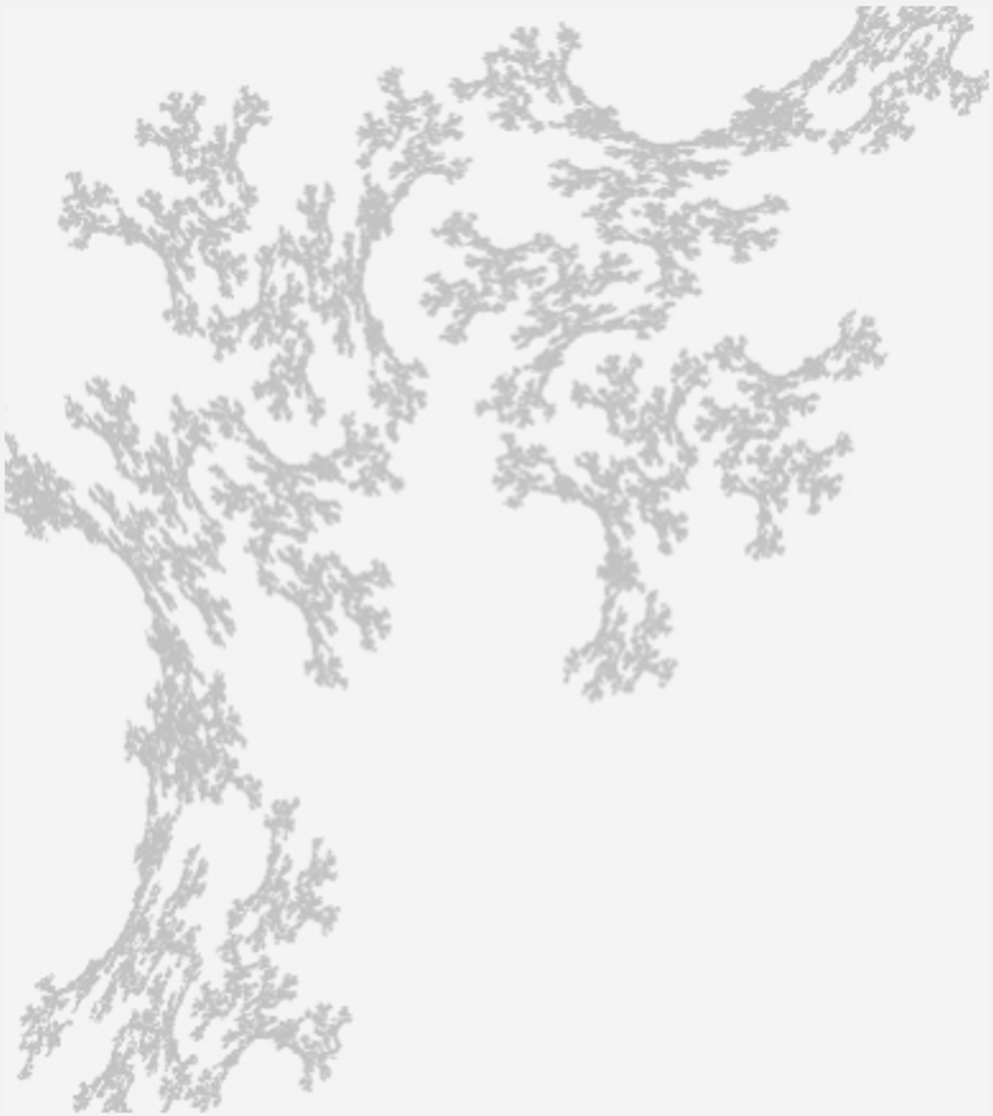
LO 3.4

Disadvantages

- Need to maintain a reference to the last node at all times
- It may be bit trickier to implement some operations such as addLast or addFirst

Advantages

- This is a great data structure to implement an application such as a multi-player game where players can be maintained in a circular linked list.
- Circular doubly linked list are used for implementation of practical data structures. (later)



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Credits: Some slides Adopted and modified from Sedgewick and Wayne

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