CC-213L

Data Structures and Algorithms

Laboratory 08

Circular and Doubly LinkedList

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Lahore, Pakistan

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Learning Objectives:

- Pointers and Dynamic Memory Allocation
- Self-Referential Objects
- Singly Circular LinkedList
- Doubly Circular LinkedList

Resources Required:

- Desktop Computer or Laptop
- Microsoft ® Visual Studio 2022

General Instructions:

- In this Lab, you are **NOT** allowed to discuss your solution with your colleagues, even not allowed to ask how is s/he doing, this may result in negative marking. You can **ONLY** discuss with your Teaching Assistants (TAs) or Lab Instructor.
- Your TAs will be available in the Lab for your help. Alternatively, you can send your queries via email to one of the followings.

Teachers:		
Course Instructor	Prof. Dr. Syed Waqar ul Qounain	swjaffry@pucit.edu.pk
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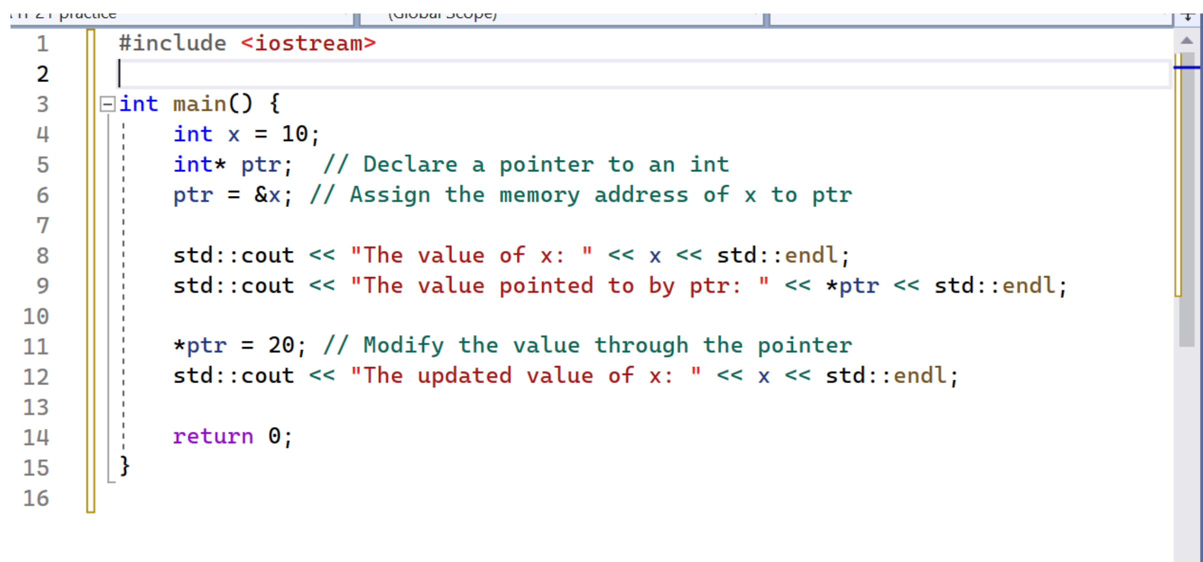
Background and Overview

Pointers and Dynamic Memory Allocation

Pointers and dynamic memory allocation are important concepts in programming, particularly in languages like C and C++. Pointers allow you to work with memory addresses, while dynamic memory allocation allows you to manage memory at runtime.

Pointers:

A pointer is a variable that stores the memory address of another variable. It allows you to indirectly access the value of the variable stored at that address. Pointers are often used for various purposes, such as dynamically allocated memory, working with arrays, and passing functions as arguments.

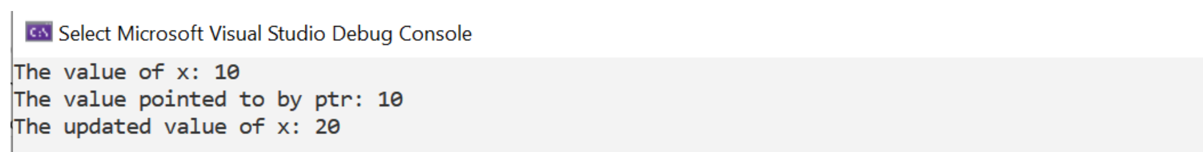


```cpp
#include <iostream>

int main() {
    int x = 10;
    int* ptr;  // Declare a pointer to an int
    ptr = &x; // Assign the memory address of x to ptr

    std::cout << "The value of x: " << x << std::endl;
    std::cout << "The value pointed to by ptr: " << *ptr << std::endl;

    *ptr = 20; // Modify the value through the pointer
    std::cout << "The updated value of x: " << x << std::endl;

    return 0;
}
```

Figure 1(Pointers)

Explanation:

In this example, ptr is a pointer to an integer, and it is assigned the memory address of the variable x. You can access and modify the value of x through the pointer using the dereference operator (*ptr).



```
Select Microsoft Visual Studio Debug Console
The value of x: 10
The value pointed to by ptr: 10
The updated value of x: 20
```

Figure 2(output)

Dynamic Memory Allocation

Dynamic memory allocation allows you to allocate memory for variables at runtime. In C++, you can use new and delete operators to allocate and deallocate memory for objects on the heap.

```cpp
#include <iostream>

int main() {
    int* dynamicArray = new int[5]; // Allocate an array of 5 integers

    for (int i = 0; i < 5; i++) {
        dynamicArray[i] = i * 10;
    }

    for (int i = 0; i < 5; i++) {
        std::cout << "dynamicArray[" << i << "] = " << dynamicArray[i] << std::endl;
    }

    delete[] dynamicArray; // Deallocate the memory

    return 0;
}
```

Figure 3(Dynamic Memory)

Explanation:

In this example, dynamicArray is allocated on the heap with space for 5 integers. After using it, it is essential to deallocate the memory using delete[] to prevent memory leaks.

Note: In modern C++ (C++11 and later), it is recommended to use smart pointers like std::unique_ptr and std::shared_ptr for better memory management, as they automatically handle memory deallocation.

```
Select Microsoft Visual Studio Debug Console
dynamicArray[0] = 0
dynamicArray[1] = 10
dynamicArray[2] = 20
dynamicArray[3] = 30
dynamicArray[4] = 40
```

Figure 4(Output)

Self-Referential Objects (Single Self Reference):

Classes that have capability to refer to their own types of objects are called **Self Referential Classes/Structs.** Objects of such classes are called self-referential Objects.

Self-referential structure in C++ are those structure that contains one or more than one pointer as their member which will be pointing to the structure of the same type. In simple words, a structure that is pointing to the structure of the same type is known as a self-referential structure.

Example in C++

```cpp
struct Node
{
    int info;
    Node* ptr;
};
```

Figure 5(Self Referencing)

Explanation:

In Figure 5 we have declared a struct Node. It has two data members info and ptr.

Info Represents the information data part. Enables the object to store relevant information in it. There can be more than one identifier of same/different datatypes depending upon the application /situation.

ptr Represents the link part. Enables the object to a self-referential object. There can be more than one such references used for different purposes in different applications /situations.

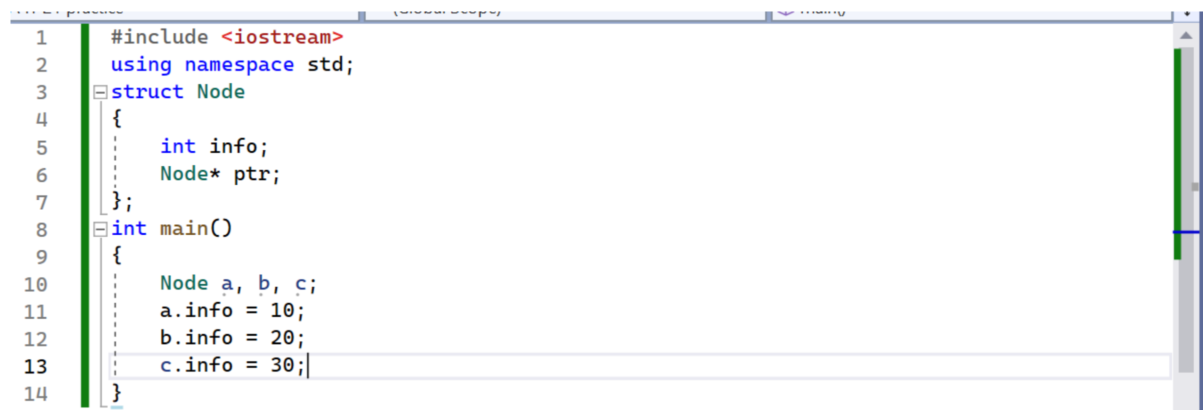


Figure 6(Self Referential Objects)

Explanation:

We have declared three Node types variables a, b and stored proper values in their info data member.

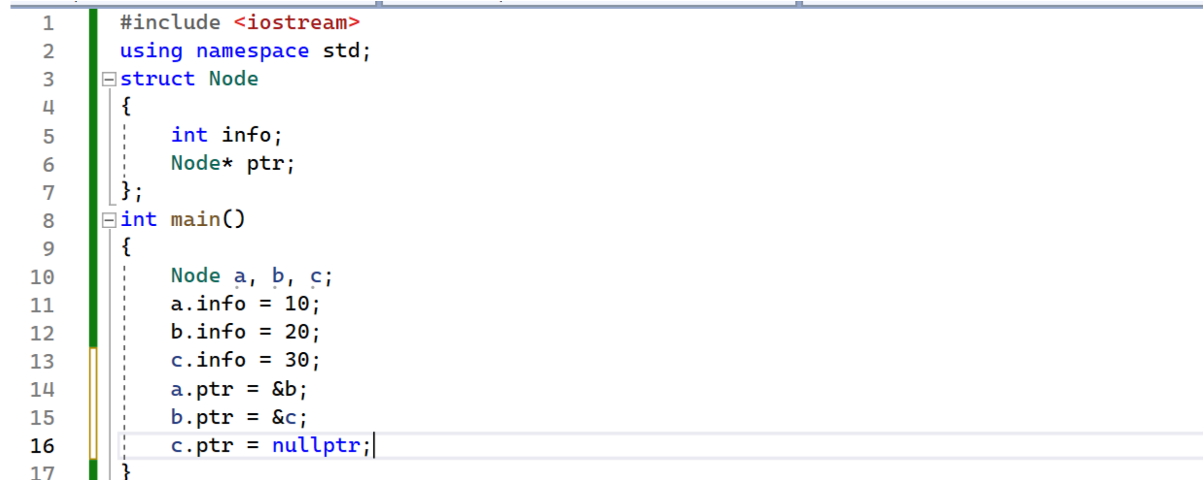


Figure 7(Self Referencing)

Explanation:

We have declared three Node types variables a, b and stored proper values in their info data member.

At line number 14 the ptr variable of type Node* (pointer to Node) is assigned the address of Node b and similarly at line 15 ptr variable of Node b is assigned addresss of Node c. ptr of Node c is pointing to null.

Some Important Operators:

- ***Member Access operators*** arrow operator (→) and dot operator (**.**) have same precedence with associativity from left to right.
- ***Dereference /indirection operator (*)*** *address* ***operator (&)*** have same precedence but associativity from right to left.
- Member access operators have high priority than indirection and address operators.

```
8   int main()
9   {
10      Node a, b, c;
11      a.info = 10;
12      b.info = 20;
13      c.info = 30;
14      a.ptr = &b;
15      b.ptr = &c;
16      c.ptr = nullptr;
17      Node* p = &a;
18      cout << p->info << endl;
19      cout << p->ptr->info << endl;
20      cout << p->ptr->ptr->info << endl;
21      
22  }
```

Figure 8(Member Access)

Explanation:

On line 17, a pointer of type Node named **p** is declared. This pointer will be used to reference **a** node. With this **p** pointer, it becomes straightforward to traverse through the linked list, as each node contains a **ptr** member that points to the next node in the sequence. We have accessed all the next node as well as information through the → (pointer member access operator).

```
Select Microsoft Visual Studio Debug Console
10
20
30
```

Figure 9(Output)

```
8  int main()
9  {
10     Node a, b, c;
11     a.info = 10;
12     b.info = 20;
13     c.info = 30;
14     a.ptr = &b;
15     b.ptr = &c;
16     c.ptr = nullptr;
17     Node* p = &a;
18     cout << (*p).info << endl;
19     cout << (*(*p).ptr).info << endl;
20     cout << (*(*(*p).ptr).ptr).info << endl;
21
22 }
```

Figure 10(Indirection Operator)

Explanation:

At line number 18,19 and 20 members have been accessing through the indirection and dot operator that is object member access operator.

```
8  int main()
9  {
10     Node a, b, c;
11     a.ptr = &b;
12     b.ptr = &c;
13     c.ptr = nullptr;
14     Node* p = &a;
15     p->info = 100;
16     p->ptr->info = 200;
17     p->ptr->ptr->info = 300;
18     while (p != nullptr)
19     {
20         cout << p->info << endl;
21         p = p->ptr;
22     }
23
24     return 0;
25 }
```

Figure 11(Traverse Nodes)

Explanation:

Rather than individually accessing information from each node, a more efficient approach is to employ a loop for traversing the nodes. This way, you can access the information in each node as long as you haven't reached a node with its **ptr** member pointing to **nullptr.**

```
Select Microsoft Visual Studio Debug Console
100
200
300
```

Figure 12(Output)

Self-Referential Objects (Double Self Reference):

Classes that have capability to refer to their own types of objects are called **Self Referential Classes/Structs.** Objects of such classes are called self-referential Objects.

Self-referential structure in C++ are those structure that contains one or more than one pointer as their member which will be pointing to the structure of the same type. In simple words, a structure that is pointing to the structure of the same type is known as a self-referential structure.

```
3   struct Node
4   {
5       int info;
6       Node* next;
7       Node* prev;
8   };
```

Figure 13(Self Reference)

Explanation:

In Figure 8 we have declared a struct Node. It has three data members info, next and prev;

Info Represents the information data part. Enables the object to store relevant information in it. There can be more than one identifier of same/different datatypes depending upon the application /situation.

next and prev Represent the link part. Enables the object to a self-referential object. There can be more than one such references used for different purposes in different applications /situations.

```
9   int main()
10  {
11
12      Node a, b,c, d, e;  // allocated on stack memory portion;
13      a.info = 1;
14      b.info = 2;
15      c.info = 3;
16      d.info = 4;
17      e.info = 5;
18      cout << a.info << " " << b.info << " " << c.info << " " << d.info << " " << e.info << endl;
19  }
```

Figure 14(Node objects)

Explanation:

At line 12 we have declared five Node objects and next lines we have initialized their info data members with proper values. At line 18 we have displayed them.

```
Select Microsoft Visual Studio Debug Console
1 2 3 4 5
```

Figure 15(Output)

```
20    a.next = &b;
21    b.next = &c;
22    c.next = &d;
23    d.next = &e;
24    b.prev = &a;
25    c.prev = &b;
26    d.prev = &c;
27    e.prev = &d;
28    e.next = a.prev = nullptr;
```

Figure 16(Double Link)

Explanation:

In Figure 11 we have initialized each Node next and previous pointer with the addresses of other nodes such that each node can refers a same node in sequence to a next node as well as previous Node.

```
29    Node* head = &a;
30    cout << "a : " << a.info << endl;
31    cout << "b : " << a.next->info << endl;
32    cout << "c : " << a.next->next->info << endl;
33    cout << "d : " << a.next->next->next->info << endl;
34    cout << "e : " << a.next->next->next->next->info << endl;
35  }
```

Figure 17(Double Links)

Output:

```
Select Microsoft Visual Studio Debug Console
a : 1
b : 2
c : 3
d : 4
e : 5
```

Figure 18(Output)

```
30    cout << "a : " << e.prev->prev->prev->prev->info << endl;
31    cout << "b : " << e.prev->prev->prev->info << endl;
32    cout << "c : " << e.prev->prev->info << endl;
33    cout << "d : " << e.prev->info << endl;
34    cout << "e : " << e.info << endl;
35  }
```

Figure 19(Previous Link)

Explanation:

In Figure 14 we have access info of a,b,c,d and e nodes through previous links of each node. This is the facility of Double links.

Some Interesting Scenarios:

```
36    Node* head = &a;
37    cout << head->next->next->prev->next->next->prev->info << endl;
38    head->next->next->prev->next->info = head->next->next->prev->next->info;
39    cout << head->next->next->prev->next->info << endl;
40    cout << (*(*((*head).next)).next->prev->next).info << endl;
41
42
```

Figure 20(Doubly Link)

Circular Singly LinkedList

A circular singly linked list is a variation of a singly linked list in which the last node of the list points back to the first node, forming a circle. In a regular singly linked list, the last node points to `null` to indicate the end of the list. However, in a circular singly linked list, the last node points to the first node, creating a circular structure.

In a circular singly linked list:

1. The last node's "next" pointer points to the first node in the list.
2. Each node in the list has a "next" pointer pointing to the next node in the sequence.
3. Traversal of the list starts from any node, and you can keep moving to the next node until you reach the starting node again.

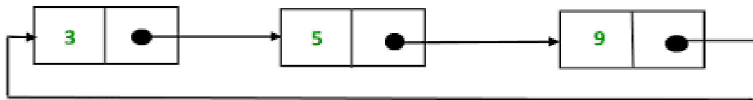


Figure 21(Circular Singly LinkedList)

```
3  class Node {
4  public:
5      int data;
6      Node* next;
7
8      Node(int value) : data(value), next(nullptr) {}
9  };
```

Figure 22(Node class)

```
58  int main()
59  {
60      Node* head = new Node(10);
61      head->next = new Node(20);
62      head->next->next = new Node(30);
63      head->next->next->next = head;
64
65      Node* temp = head;
66      while (temp->next != head)
67      {
68          cout << temp->data << endl;
69          temp = temp->next;
70      }
71      cout << temp->data << endl;
72
73      return 0;
74  }
```

Figure 23(Circular Singly LinkedList)

Output

```
Select Microsoft Visual Studio Debug Console
10
20
30
```

Figure 24(Output)

Circular Doubly LinkedList

A circular doubly linked list is a type of linked list in which each node in the list contains data, a pointer to the next node, and a pointer to the previous node. The circular doubly linked list is similar to a regular doubly linked list, but in this case, the last node points back to the first node, forming a circular structure.

In a circular doubly linked list:

Each node has three components: data, a "next" pointer pointing to the next node, and a "previous" pointer pointing to the previous node.

The "next" pointer of the last node in the list points to the first node, and the "previous" pointer of the first node points to the last node, creating a circular connection.

```
59  class Node
60  {
61  public:
62      int data;
63      Node* next;
64      Node* prev;
65
66      Node(int value) : data(value), next(nullptr), prev(nullptr) {}
67  };
```

Figure 25(Doubly LinkedList Node)

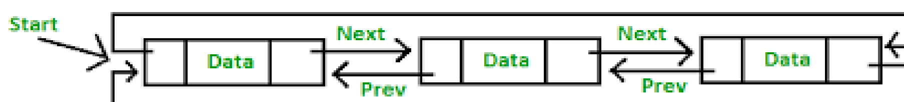


Figure 26(Circular Doubly LinkedList)

```
69  int main()
70  {
71      Node* head = new Node(10);
72      head->next = new Node(20);
73      head->next->prev = head;
74      head->next->next = head;
75
76      cout << head->next->prev->data << endl; // 10
77
78      cout << head->next->next->next->data << endl;
79      return 0;
80  }
```

Figure 27(Doubly LinkedList)

Activities

Pre-Lab Activities:

Task 01: Circular Singly LinkedList implementation

In previous Lab you have implemented Singly Linear LinkedList. Modify implementation of that LinkedList and make it ***circular Singly LinkedList.***

```
template<class T>
class LinkedList;
template<class T>
class Node
{
public:
        T info;
        Node<T>* next;
        // Methods...
};

template<class T>
class LinkedList
{
        Node<T>* head;

        // Methods...
};
```

Implement following functions for List class.

1. **Constructor, destructor, Copy-constructor.**
2. **void insertAtHead(T value)**
3. **void insertAtTail(T value)**
4. **bool deleteAtHead( )**
5. **bool deleteAtTail( )**
6. **void printList( )**
7. **Node* getNode(int n)**

   This function should return pointer to nth node in the list. Returns last node if n is greater than the number of nodes present in the list.

8. **bool insertAfter(T value, T key)**

   Insert a node after some node whose info equals input parameter key and returns true if node is successfully inserted, false otherwise.

9. **bool insertBefore(T value, T key)**

   Insert a node before some node whose info equals input parameter key and returns true if node is successfully inserted, false otherwise.

10. **bool deleteBefore(T key)**

Delete a node that is before some node whose info equals input parameter key and returns true if node is successfully inserted, false otherwise. Check boundary cases i.e if node to be deleted is last node or first node in the list.

11. **bool deleteAfter(T value)**

    Delete a node that is after some node whose info equals input parameter key and returns true if node is successfully inserted, false otherwise. Check boundary cases i.e if node to be deleted is last node or first node in the list.

12. **int getLength( )** returns the total number of nodes in the list.
13. **Node* search(T x)**

    Search a node with value “x” from list and return its link. If multiple nodes of same value exist, then return pointer to first node having the value “x”.

In-Lab Activities

Task 01 Circular Doubly LinkedList

Give the implementation of a class named **CDLLD** for a **Circular Doubly Linked List (with a dummy header node)** which stores integers in **unsorted order**.

Your class definitions should look like:

```
class CDLLD;
class DNode{

        friend class CDLLD;
    private:

        int data;

        DNode* next;

        DNode* prev;

};


class CDLLD{                    // Circular Doubly Linked List with a Dummy header node

    private:

        DNode head;             // Dummy header node

    public:

        CDLLD ();               // Default constructor

        ~CDLLD ();              // Destructor

        ...

};
```

Apart from the **default constructor** and **destructor**, the **CDLLD** class should also have the following public member functions:

1. **bool insertAtStart (int val)** **Time complexity:** $O(1)$

   This function should insert **val** at the start of the LinkedList

2. **bool insertAtEnd (int val)** **Time complexity:** $O(1)$

   This function should insert **val** at the end of the linked list.

3. **void display ()**

   This function should display the contents of linked list on screen.

4. **int countNodes ()**

   This function should determine (and return) the count of nodes present in the linked list.

Task 02 Combine Lists

Implement the following public member function of the **CDLLD** class:

void combine (CDLLD& list1, CDLLD& list2) **Time complexity: $O(1)$**

This function will combine the nodes of the two linked lists (**list1** and **list2**) into one list. All the nodes of the first list (**list1**) will precede (come before) all the nodes of the second list

(**list2**). The time complexity of this function must be **constant** i.e., $O(1)$.

For example, if **list1** contain **{7 3 4 2}** and **list2** contains **{5 9}**, then after the function call:

list3.combine(list1,list2);

list3 should contain **{7 3 4 2 5 9}** and **list1** and **list2** should be empty now.

Very Important: *You are NOT allowed to create any new node in this function. You are also NOT allowed to modify the "data" field of any node. You can assume that the CDLLD object on which this function is called is empty at the start of this function.*

Also write a driver main function to test the working of the above function.

Task 03 Shuffle Merge

Implement the following public member function of the **CDLLD** class:

void shuffleMerge (CDLLD& list1, CDLLD& list2)

This function will merge the nodes of the two linked lists (**list1** and **list2**) to make one list, by taking nodes alternately from the two lists.

For example, if **list1** contains **{2 6 4}** and **list2** contains **{8 1 3}**, then after the function call:

list3.shuffleMerge(list1,list2);

list3 should contain **{2 8 6 1 4 3}** and **list1** and **list2** should be empty now.

Very Important: *You are NOT allowed to create any new node in this function. You are also NOT allowed to modify the "data" field of any node. You can assume that both lists (which are being merged) contain the **same number of elements/nodes**. You can also assume that the CDLLD object on which this function is called is empty at the start of this function.*

Also write a driver main function to test the working of the above function.

Task 04 Split List

Implement the following public member function of the **CDLLD**class:

void splitList (CDLLD& leftHalf, CDLLD& rightHalf)
This function will split the list (on which it is called) into two halves, and store these halves in thetwo linked lists passed into this function. Make sure that all boundary cases are properly handled.

For example, if **list1** contains **{8 4 2 9 1 5 3}** and **list2** and **list3** are empty, then after thefunction call:

list1.splitList(list2,list3);

list2 should contain **{8 4 2 9}** and **list3** should contain **{1 5 3}** and **list1** should be empty now. *Note that if the list contains an ODD number of elements, then the one extra element shouldgo into the **left half**.*

Very Important: *You are NOT allowed to create any new node in this function. You are also NOTallowed to modify the "data" field of any node. You can assume that the CDLLD objects being passed into this function are empty at the start of this function.*

Also write a driver main function to test the working of the above function.

Post-Lab Activities

Task 01 Sorted List

Implement the following public member function of the **CDLLD** class:

bool isSorted () const

This function should determine whether the linked list is **sorted in increasing order** or not. It should return **true** if the values of the linked list are sorted in increasing order. Otherwise, it should return **false**.

Task 02 Remove Last Node

Implement the following public member function of the **CDLLD** class:

bool removeLastNode (int& val) **Time complexity: $O(1)$**

This function will remove the *last node* from the linked list. Before deallocating the node, this function should store the data present in that node into the reference parameter **val**. This function should return **false** if the list is empty; otherwise, it should remove the last node of the linked list and return **true**.

Task 03 Remove Second Last Node

Implement the following public member function of the **CDLLD** class:

bool removeSecondLastNode (int& val) **Time complexity: $O(1)$**

This function will remove the *second last node* from the linked list. Before deallocating the node, this function should store the data present in that node into the reference parameter **val**. This function should return **false** if the list contains fewer than two nodes; otherwise, it should remove the second last node of the linked list and return **true**. (*Note:* You are NOT allowed to modify the data of any node in the linked list).

Task 04 Remove Kth Node

Implement the following public member function of the **CDLLD** class:

bool removeKthNode (int k, int& val)

This function will remove the **k**th element (node) from the linked list. For example, if the **CDLLD** object **list** contains these 8 values **{4 2 8 1 9 5 4 6}**, then the function call:

list.removeKthNode(4,val);

This function should remove the 4th element (node) from the linked list and the resulting **list** should contain these 7 values: **{4 2 8 9 5 4 6}**. Before deallocating the node, this function should store the data present in that node into the reference parameter **val**.

This function should return **false** if the linked list contains fewer than **k** elements; otherwise it should remove the **k**th node from the linked list and return **true**. (*Note:* You are NOT allowed to modify the data of any node in the linked list).

Also write a driver main function to test the working of the above functions.

Submissions:

- For In-Lab Activity:
  - Save the files on your PC.
  - TA's will evaluate the tasks offline.
- For Pre-Lab & Post-Lab Activity:
  - Submit the .cpp file on Google Classroom and name it to your roll no.

Evaluations Metric:

- All the lab tasks will be evaluated offline by TA's
- **Division of Pre-Lab marks:** **[50 marks]**
  - Task 01: Circular Singly LinkedList Implementation [50 marks]
- **Division of In-Lab marks:** **[40 marks]**
  - Task 01: Doubly LinkedList Implementation [25 marks]
  - Task 02: Combine Lists [05 marks]
  - Task 03: Shuffle Merge [05 marks]
  - Task 04: Split List [05 marks]
- **Division of Post-Lab marks:** **[40 marks]**
  - Task 01: Sorted List [10 marks]
  - Task 02: Remove Last Node [10 marks]
  - Task 03: Remove Second Last Node [10 marks]
  - Task 04: Remove Kth Nodes [10 marks]

References and Additional Material:

Circular Singly LinkedList

https://www.geeksforgeeks.org/circular-linked-list/

Circular Doubly LinkedList

https://www.geeksforgeeks.org/introduction-to-circular-doubly-linked-list/

Lab Time Activity Simulation Log:

- Slot – 01 – 02:00 – 00:15: Class Settlement
- Slot – 02 – 02:15 – 02:30: In-Lab Task 01
- Slot – 03 – 02:30 – 02:45: In-Lab Task 01
- Slot – 04 – 02:45 – 03:00: In-Lab Task 01
- Slot – 05 – 03:00 – 03:15: In-Lab Task 01
- Slot – 06 – 03:15 – 03:30: In-Lab Task 02
- Slot – 07 – 03:30 – 03:45: In-Lab Task 02
- Slot – 08 – 03:45 – 04:00: In-Lab Task 03
- Slot – 09 – 04:00 – 04:15: In-Lab Task 03
- Slot – 10 – 04:15 – 04:30: In-Lab Task 04
- Slot – 11 – 4:300 – 04:45: In-Lab Task 04
- Slot – 12 – 04:45 – 05:00: Discussion on Post-Lab