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DATA STRUCTURE & ALGORITHM

Chapter 07 -

Linked List

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Objectives

At the end of the class, students are expected to :

- Describe linear list concepts using array and linked list.
- Able to lists variations of linked list and basic operations of linked lists.
- Able to explain in detail the implementation and operations of link lists using pointers.
- Able to write program that can implement linked list concept.

Introduction

Lists Definition

- Lists is a group of objects which is organized in sequence.
- List categories: linear list and nonlinear list.
- Linear list – a list in which the data is organized in sequence, example: array, linked list, stack and queue
- Non-Linear list – a list in which the data is stored not sequence, example: tree and graph

Introduction to Linear List

- **Array and linked** lists are linear lists that doesn't have any restrictions while implementing operations such as, insertion, deletion and accessing data in the lists.
- The operations can be done in any parts of the lists, either in the front lists, in the middle or at the back of the lists.

- **Stack and queue** is a linear lists that has restrictions while implementing its operations.
  - **Stack** – to insert, delete and access data can only be done at the top of the lists.
  - **Queue** - Insert data in a queue can be done at the back of the lists while to delete data from a queue can only be done at the front list.

Introduction to Linear List

Pelajar

Indeks	Nama	Kursus	Tahun
[0]	Aziz Nabil	Sains Komputer	2
[1]	Boh Guan	Sains Komputer	1
[2]	Durrani Nukman	Kej. Elektrik	3
[3]	Mohd Saufi	Sains Pendidikan	2
[4]	Nafisah Nordin	Sains Komputer	1
[5]	Safinatun Najah	Pengurusan Komputer	3
[6]			
[7]			

- An array named Pelajar which contains attributes nama pelajar, kursus and tahun Pelajar.
- The array is sorted and can only be accessed based on the index or subscript of the array.
- Example: to access information for a student named Mohd Saufi, we can use:

  Pelajar[3].Nama, Pelajar[3].Kursus dan Pelajar[3].Tahun.

Introduction to Linear List

- Linked lists which contain several nodes which is sorted in ascendeng order.
- Each node contains at least
  - A piece of data (any type)
  - Pointer to the next node in the list
- Need pointer variable *Head [Senarai]*: to point to the first node

Introduction to Linear List

- Basic operations for linear lists:
  - Insert new data in the lists.
  - Delete data from a lists.
  - Update data in the list.
  - Sort data in the lists and
  - Find data in the list.

Array as linear list

- Sized is fixed during array declaration.
- Data insertion is limited to array size
- In order to insert data, need to check whether the array is full or not. If the array is full, the insertion cannot be done.

Array as linear list

- Data in the array can be accessed at random using the index of the array.
- Example, if we access Nama, Kursus and Tahun for Pelajar[3] information of Pelajar[3], Mohd Saufi taking Sains Pendidikan course and in year 2 will be given.
- By random access, accessing data in an array can be done faster.

Pelajar

Indeks	Nama	Kursus	Tahun
[0]	Aziz Nabil	Sains Komputer	2
[1]	Boh Guan	Sains Komputer	1
[2]	Durrani Nukman	Kej. Elektrik	3
[3]	Mohd Saufi	Sains Pendidikan	2
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[5]	Safinatun Najah	Pengurusan Komputer	3
[6]			
[7]			

Array Implementation … the drawbacks

- Requires an estimate of the maximum size of the list
  - waste space
- printList and find: linear access
- findKth: constant
- insert and delete: slow
  - insert at position 0 (making a new element)
    - requires first pushing the entire array down one spot to make room
  - delete at position 0
    - requires shifting all the elements in the list up one
  - On average, half of the lists needs to be moved for either operation

Array Implementation … the drawbacks

- Need space to insert item in the middle of the list.
- Insert Fatimah Adam in between students named Durrani Nukman and Mohd Saufi.
- insert at index 3 : requires first pushing the entire array from index 3 down one spot to make room

Pelajar

Indeks	Nama	Kursus	Tahun
[0]	Aziz Nabil	Sains Komputer	2
[1]	Boh Guan	Sains Komputer	1
[2]	Durrani Nukman	Kej. Elektrik	3
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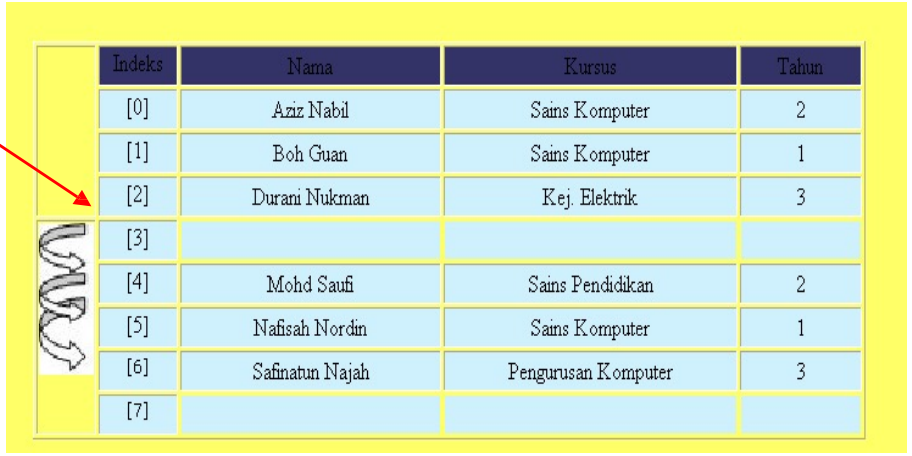
[6]			
[7]			



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Array Implementation … the drawbacks

Indeks	Nama	Kursus	Tahun
[0]	Aziz Nabil	Sains Komputer	2
[1]	Boh Guan	Sains Komputer	1
[2]	Durani Nukman	Kej. Elektrik	3
[3]	Fatimah Adam	Kej. Awam	2
[4]	Mohd Saufi	Sains Pendidikan	2
[5]	Nafisah Nordin	Sains Komputer	1
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[7]			

New item is inserted at index 3, after shifting the data from index 3 onwards. .

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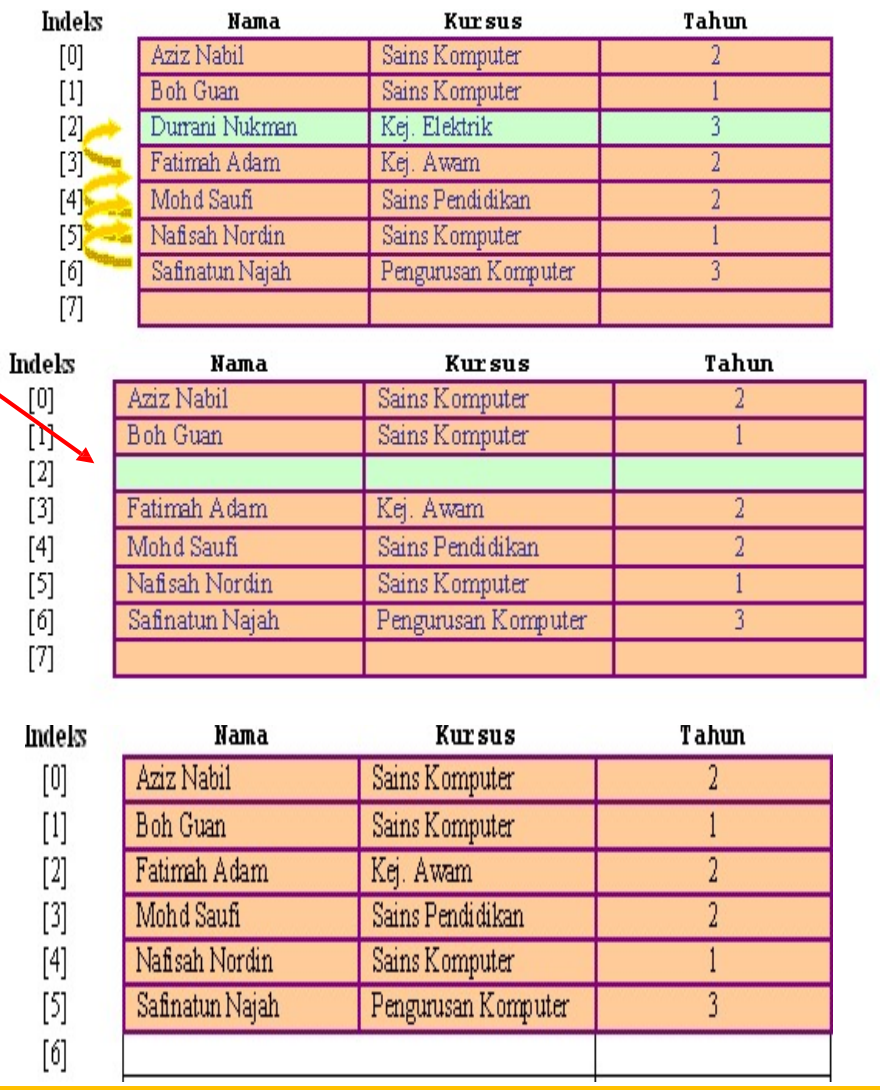
Array Implementation … the drawbacks

To delete item in the middle of the array will leave a blank space in the middle.

It requires shifting all the elements in the list up one in order to eliminate the space..

Example: when information about Durrani Nukman is deleted, all elements below it, is shifted up.



Indeks	Nama	Kursus	Tahun
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[3]	Fatimah Adam	Kej. Awam	2
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[6]			

Pointer Implementation (Linked List)

- Ensure that the list is not stored contiguously
  - use a linked list
  - a series of structures that are not necessarily adjacent in memory
- Each node contains the element and a pointer to a structure containing its successor
  - the last cell's next link points to NULL
- Compared to the array implementation,
  - the pointer implementation uses only as much space as is needed for the elements currently on the list
  - but requires space for the pointers in each cell

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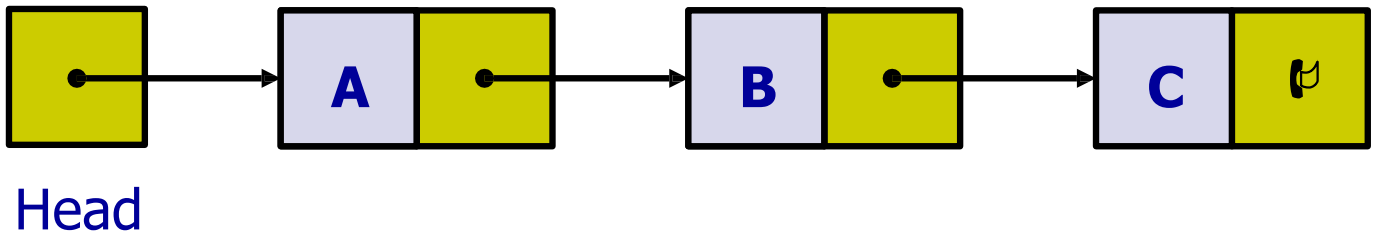
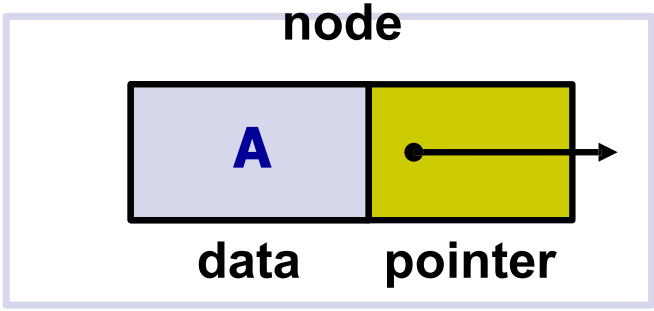
Linked list variations

- Singly linked list
- Doubly linked list
- Circular linked list
- Circular doubly linked list
- Sorted linked list
- Unsorted linked list

Singly Linked Lists



- A *linked list* is a series of connected *nodes*
- Each node contains at least
  - A piece of data (any type)
  - Pointer to the next node in the list
- *Head*: pointer to the first node
- The last node points to `NULL`



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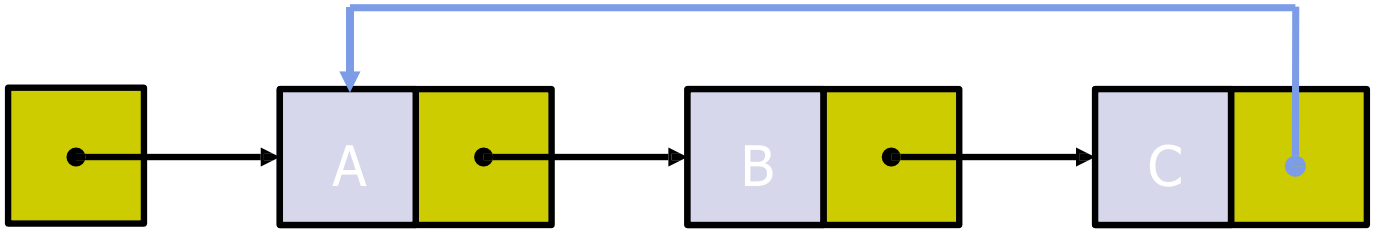
Variations of Linked Lists

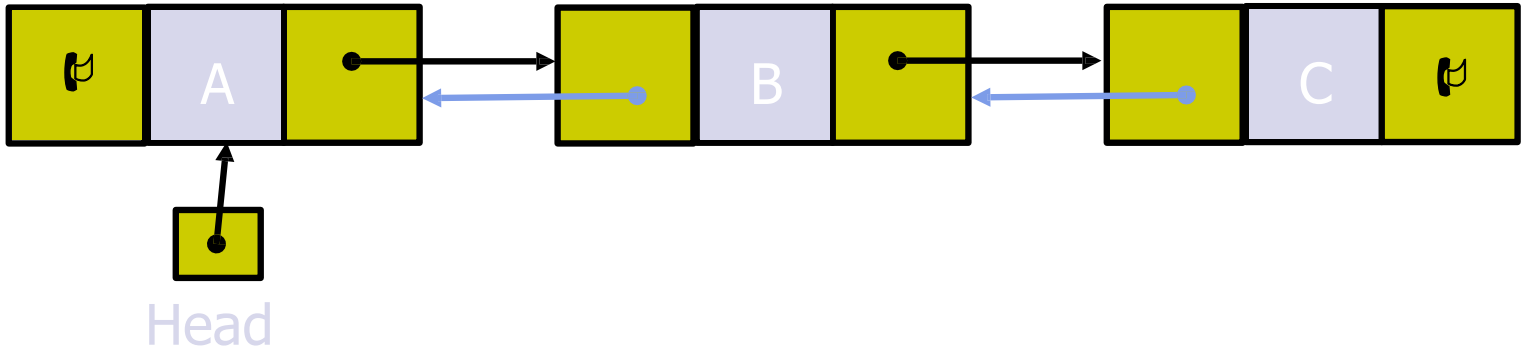
- *Circular linked lists*
  - The last node points to the first node of the list



- How do we know when we have finished traversing the list? (Tip: check if the pointer of the current node is equal to the head.)

Variations of Linked Lists

- *Doubly linked lists*
  - Each node points to not only successor but the predecessor
  - There are two `NULL:` at the first and last nodes in the list
  - Advantage: given a node, it is easy to visit its predecessor. Convenient to traverse lists backwards



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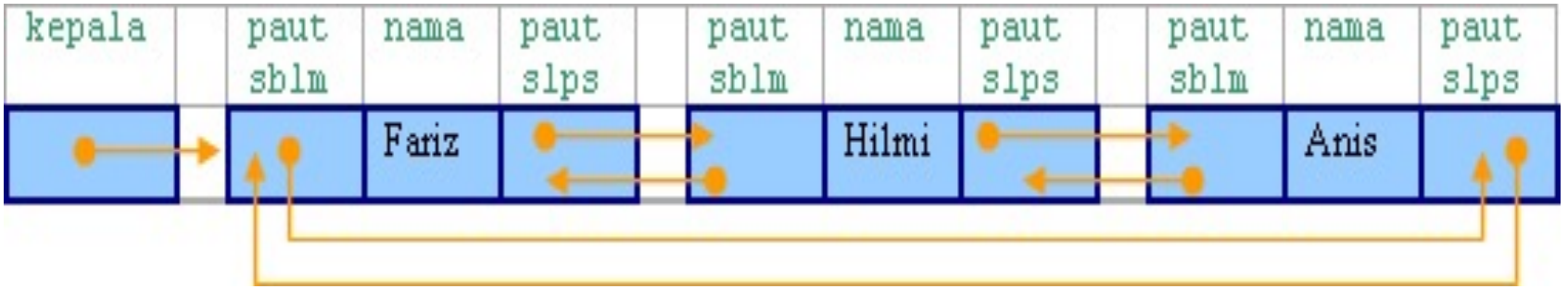
Variations of Linked Lists

Circular doubly linked list

- No `NULL` value at the first and last nodes in the list
- Convenient to traverse lists backwards and forwards



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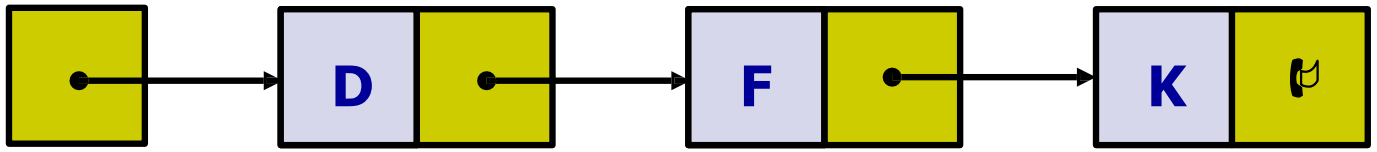
Variations of Linked Lists

Sorted Linked list :

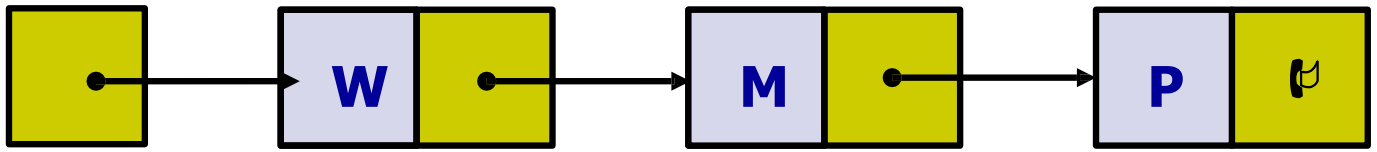
The nodes in the lists is sorted in certain order.



Head

UnSorted Linked list :

The nodes in the lists is not sorted in any order.



Head

LINK LIST IMPLEMENTATION

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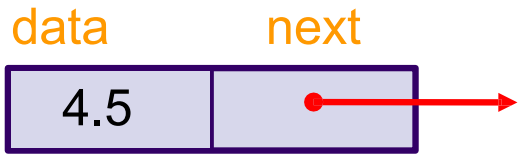
Linked List Implementation

- We need two classes: **Node** and **List**
- Declare `Node` class for the nodes which contains `data` and `next`: a pointer to the next node in the list

```
class Node {
public:
        double data;          // data
        Node* next;           // pointer to next node
};
```



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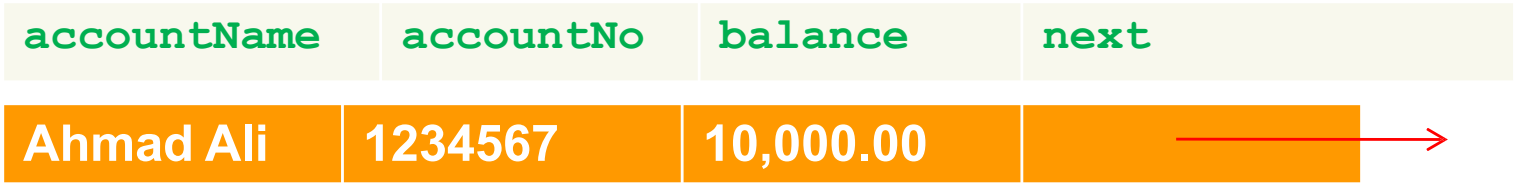
Example :
Declaring a node for class account

Create a node for class account using struct

```
struct nodeAccount {
        char accountName[20];
        char accountNo[15];
        float balance;
        nodeAccount *next;
};
```



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Exercise – Declaring a node

bookTitle	ISBNno	price	next
Link List Guide	1234-5678	40.00	NULL

Figure above represents a node in a link list that store information for book.
The node consists of the following attributes :

bookTitle, ISBNno, price and pointer next.

Write a class/struct declaration for the node that is able to store the information.

A Simple Linked List Class

- Declare `List`, which contains
  - `head`: a pointer to the first node in the list.
    Since the list is empty initially, `head` is set to `NULL`
  - Operations on `List`

```
class List {
public:
        List(void) { head = NULL; }          // constructor
        ~List(void);                         // destructor

        bool IsEmpty() { return head == NULL; }
        Node* InsertNode(double x);
        int FindNode(double x);
        int DeleteNode(double x);
        void DisplayList(void);
private:
        Node* head;
};
```

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A Simple Linked List Class

Operations of `List`

- **`IsEmpty`**: determine whether or not the list is empty
- **`InsertNode`**: insert a new node at a particular position
- **`FindNode`**: find a node with a given value
- **`DeleteNode`**: delete a node with a given value
- **`DisplayList`**: print all the nodes in the list

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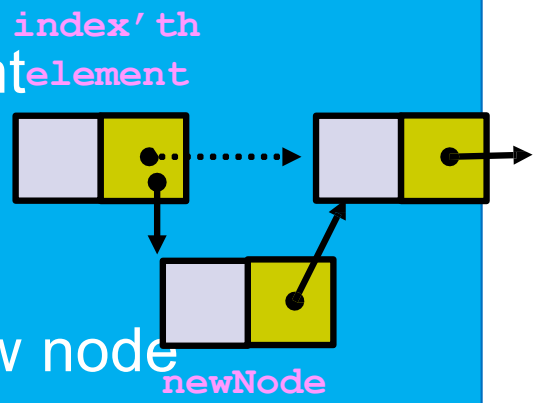
Inserting a new node

X

- `Node* InsertNode(double x)`
  - Insert a node with data equal to `x`. After insertion, this function generates a sorted list : in ascending order.
  - Find the location of the value to be inserted so that the value will be in the correct order in the list. **(i.e., when `index = 0`, insert the node as the first element; when `index = 1`, insert the node after the first element, and so on)**
- Steps
  1. Locate `position to insert` the element
  2. Allocate memory for the new node
  3. Point the new node to its successor
  4. Point the new node's predecessor to the new node



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Inserting a new node

- Possible cases of `InsertNode`
  1. Insert into an empty list
  2. Insert in front
  3. Insert at back
  4. Insert in middle
- But, in fact, only need to handle two cases
  - Insert as the first node (Case 1 and Case 2)
  - Insert in the middle or at the end of the list (Case 3 and Case 4)

Inserting a new node (will create a sorted list)

```
Node* List::InsertNode(double x) {
    int  currIndex  =       0;
    Node* currNode =        head;
    Node* prevNode =        NULL;
    while (currNode && x > currNode->data) {
            prevNode = currNode;
            currNode = currNode->next;
            currIndex++;
    }
    Node* newNode   =       new     Node;
    newNode->data   =       x;
    if (currIndex == 0) {
            newNode->next   =       head;
            head            =       newNode;
    }
    else {
            newNode->next   =       prevNode->next;
            prevNode->next =        newNode;
    }
    return newNode;
}
```

Try to locate the index of the node being inserted.

Inserting a new node

```
Node* List::InsertNode(double x) {

        int  currIndex  =       0;
        Node* currNode =        head;
        Node* prevNode =        NULL;
        while (currNode && x > currNode->data) {
                prevNode = currNode;
                currNode = currNode->next;
                currIndex++;
        }

        Node* newNode   =       new     Node;
        newNode->data   =       x;
        if (currIndex == 0) {
                newNode->next   =       head;
                head            =       newNode;
        }
        else {
                newNode->next   =       prevNode->next;
                prevNode->next  =       newNode;
        }
        return newNode;
}
```

Create a new node

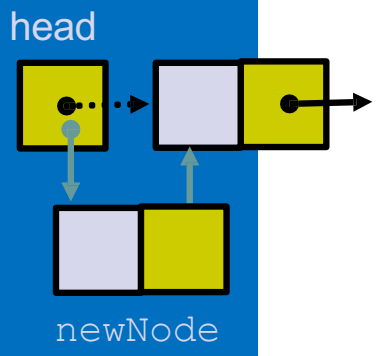
Inserting a new node

```
Node* List::InsertNode(double x) {

        int  currIndex  =       0;
        Node* currNode =        head;
        Node* prevNode =        NULL;
        while (currNode && x > currNode->data) {
                prevNode = currNode;
                currNode = currNode->next;
                currIndex++;
        }

        Node* newNode   =       new     Node;
        newNode->data   =       x;
        if (currIndex == 0) {
                newNode->next   =       head;
                head            =       newNode;
        }
        else {
                newNode->next   =       prevNode->next;
                prevNode->next  =       newNode;
        }
        return newNode;
}
```

Insert as first element

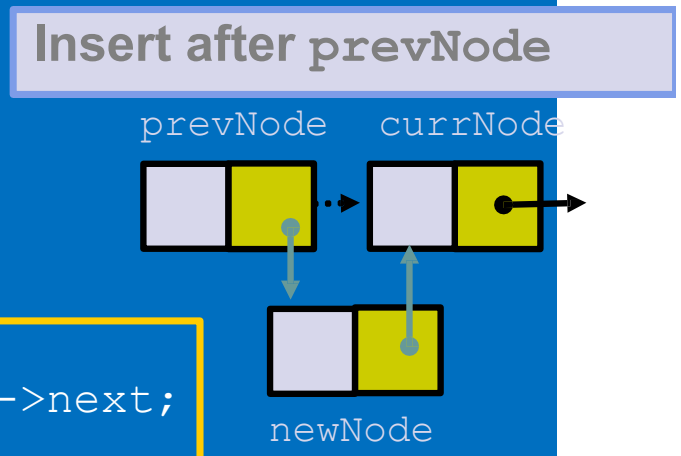


Inserting a new node

```
Node* List::InsertNode(double x) {

        int  currIndex  =       0;
        Node* currNode =        head;
        Node* prevNode =        NULL;
        while (currNode && x > currNode->data) {
                prevNode = currNode;
                currNode = currNode->next;
                currIndex++;
        }

        Node* newNode   =       new     Node;
        newNode->data   =       x;
        if (currIndex == 0) {
                newNode->next   =       head;
                head            =       newNode;
        }
        else {
                newNode->next   =       prevNode->next;
                prevNode->next =        newNode;
        }
        return newNode;
}
```



Inserting a new node at certain index (will create unsorted list)

```
Node* List::InsertNode(int index, double x) {
    if (index < 0) return NULL;

    int currIndex  =      1;
    Node* currNode =      head;
    while (currNode && index > currIndex) {
        currNode       =      currNode->next;
        currIndex++;
    }
    if (index > 0 && currNode == NULL) return NULL;

    Node* newNode  =      new    Node;
    newNode->data  =      x;
    if (index == 0) {
        newNode->next  =      head;
        head           =      newNode;
    }
    else {
        newNode->next  =      currNode->next;
        currNode->next =      newNode;
    }
    return newNode;
```

Try to locate `index`'th node. If it doesn't exist, return `NULL`.

Inserting a new node

```
Node* List::InsertNode(int index, double x) {
        if (index < 0) return NULL;

        int currIndex  =       1;
        Node* currNode =       head;
        while (currNode && index > currIndex) {
                currNode       =       currNode->next;
                currIndex++;
        }
        if (index > 0 && currNode == NULL) return NULL;

        Node* newNode  =       new     Node;
        newNode->data  =       x;
        if (index == 0) {
                newNode->next  =       head;
                head           =       newNode;
        }
        else {
                newNode->next  =       currNode->next;
                currNode->next =       newNode;
        }
        return newNode;
```

Create a new node

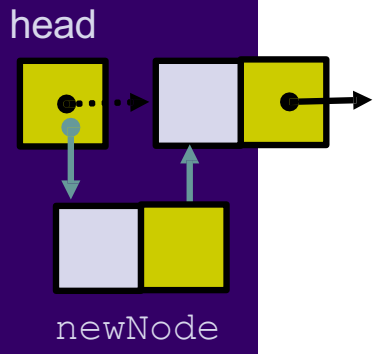
Inserting a new node

```
Node* List::InsertNode(int index, double x) {
        if (index < 0) return NULL;

        int currIndex  =       1;
        Node* currNode =       head;
        while (currNode && index > currIndex) {
                currNode       =       currNode->next;
                currIndex++;
        }
        if (index > 0 && currNode == NULL) return NULL;

        Node* newNode  =       new     Node;
        newNode->data  =       x;
        if (index == 0) {
                newNode->next  =       head;
                head           =       newNode;
        }
        else {
                newNode->next  =       currNode->next;
                currNode->next =       newNode;
        }
        return newNode;
```

Insert as first element



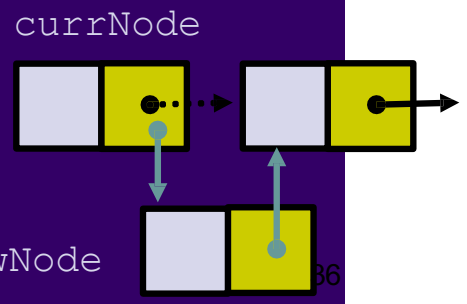
Inserting a new node

```
Node* List::InsertNode(int index, double x) {
        if (index < 0) return NULL;

        int currIndex  =       1;
        Node* currNode =       head;
        while (currNode && index > currIndex) {
                currNode       =       currNode->next;
                currIndex++;
        }
        if (index > 0 && currNode == NULL) return NULL;

        Node* newNode  =       new     Node;
        newNode->data  =       x;
        if (index == 0) {
                newNode->next  =       head;
                head           =       newNode;
        }
        else {
                newNode->next  =       currNode->next;
                currNode->next =       newNode;
        }
        return newNode;
```

Insert after currNode



Finding a node

- `int FindNode(double x)`
  - Search for a node with the value equal to `x` in the list.
  - If such a node is found, return its position. Otherwise, return 0.

```
int List::FindNode(double x) {
        Node* currNode      =      head;
        int currIndex=      1;
        while (currNode && currNode->data != x) {
                currNode      =      currNode->next;
                currIndex++;
        }
        if (currNode)
                return currIndex;
        else
                return 0;
}
```

Deleting a node

- `int DeleteNode(double x)`
  - Delete a node with the value equal to `x` from the list.
  - If such a node is found, return its position. Otherwise, return 0.
- Steps
  - Find the desirable node (similar to `FindNode`)
  - Release the memory occupied by the found node
  - Set the pointer of the predecessor of the found node to the successor of the found node
- Like `InsertNode`, there are two special cases
  - Delete first node
  - Delete the node in middle or at the end of the list

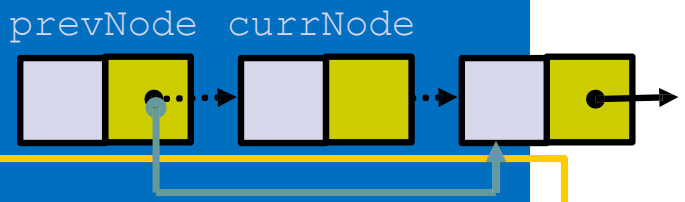
Deleting a node

```
int List::DeleteNode(double x) {
        Node* prevNode =        NULL;
        Node* currNode =        head;
        int currIndex  =        1;
        while (currNode && currNode->data != x) {
                prevNode        =       currNode;
                currNode        =       currNode->next;
                currIndex++;
        }
        if (currNode) {
                if (prevNode) {
                        prevNode->next =        currNode->next;
                        delete currNode;
                }
                else {
                        head            =       currNode->next;
                        delete currNode;
                }
                return currIndex;
        }
        return 0;
```

Try to find the node with its value equal to `x`

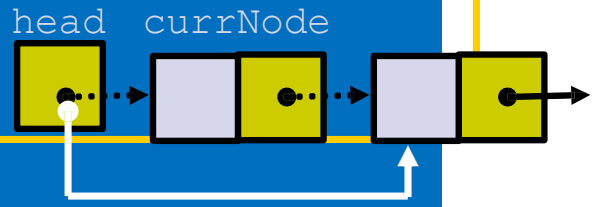
Deleting a node

```
int List::DeleteNode(double x) {
        Node* prevNode =        NULL;
        Node* currNode =        head;
        int currIndex  =        1;
        while (currNode && currNode->data != x) {
                prevNode        =       currNode;
                currNode        =       currNode->next;
                currIndex++;
        }
        if (currNode) {
                if (prevNode) {
                        prevNode->next =        currNode->next;
                        delete currNode;
                }
                else {
                        head            =       currNode->next;
                        delete currNode;
                }
                return currIndex;
        }
        return 0;
}
```



Deleting a node

```
int List::DeleteNode(double x) {
        Node* prevNode =        NULL;
        Node* currNode =        head;
        int currIndex  =        1;
        while (currNode && currNode->data != x) {
                prevNode        =       currNode;
                currNode        =       currNode->next;
                currIndex++;
        }
        if (currNode) {
                if (prevNode) {
                        prevNode->next =        currNode->next;
                        delete currNode;
                }
                else {
                        head    = currNode->next;
                        delete currNode;
                }
                return currIndex;
        }
        return 0;
}
```



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Printing all the elements

- **void DisplayList(void)**
  - Print the data of all the elements
  - Print the number of the nodes in the list

```
void List::DisplayList()
{
    int num             =       0;
    Node* currNode      =       head;
    while (currNode != NULL){
        cout << currNode->data << endl;
        currNode        =       currNode->next;
        num++;
    }
    cout << "Number of nodes in the list: " << num << endl;
}
```

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Destroying the list : `~List()`

- Use the destructor to release all the memory used by the list.
- Step through the list and delete each node

```
List::~List()
{   Node* currNode = head, *nextNode = NULL;
    while (currNode != NULL)
    {    nextNode = currNode->next;
         // destroy the current node
         delete currNode;
         currNode = nextNode;
    }
    head = Null;
}
```

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Using List

```
int main(void)
{
        List list;
        list.InsertNode(7.0); // successful
        list.InsertNode(5.0); // successful
        list.InsertNode(6.0); // successful
        list.InsertNode(4.0); // successful
        // print all the elements
        list.DisplayList();
        if(list.FindNode(5.0)  > 0) cout << "5.0 found" << endl;
        else                        cout << "5.0 not found" << endl;
        if(list.FindNode(4.5)  > 0) cout << "4.5 found" << endl;
        else                        cout << "4.5 not found" << endl;
        list.DeleteNode(7.0);
        list.DisplayList();
        return 0;
}
```

result

```
4
5
6
7
Number of nodes in the list: 4
5.0 found
4.5 not found
4
5
6
Number of nodes in the list: 3
```

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- Linked lists are more complex to code and manage than arrays, but they have some distinct advantages.
  - Dynamic: a linked list can easily grow and shrink in size.
    - We don't need to know how many nodes will be in the list. They are created in memory as needed.
    - In contrast, the size of a C++ array is fixed at compilation time.

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Easy and fast insertions and deletions

- To insert or delete an element in an array, we need to copy to temporary variables to make room for new elements or close the gap caused by deleted elements.
- With a linked list, no need to move other nodes. Only need to reset some pointers.

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Linked List - Conclusion

- Try make your own conclusion by comparing array list and linked list in term of:
  - Size of items/nodes in the list
  - Add new items/nodes at the beginning or in the middle of the list
  - Delete items at the beginning or in the middle of the list
  - Get items at nodes *n*

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Lab Exercise

- Write a complete link list program based on the implementation of the following classes and functions given in the notes.
  - Class **`Node`** and **`List`**
  - **`Constructor`** and **`Destructor`**
  - **`IsEmpty()`**,**`InsertNode()`**, **`FindNode()`** **`DeleteNode()`** and **`DisplayList()`**
  - Provide main() program to execute the list.

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Thank You

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