

**Time budget:** 25 minutes

**Task:** Work alone through this learning exercise. Follow the working instructions marked with a pen. The learning exercise consists of eight parts. You will probably not be able to finish everything during the lecture. If you get up to part number four it's already fine. Finishing this paper will be part of exercise number eleven.

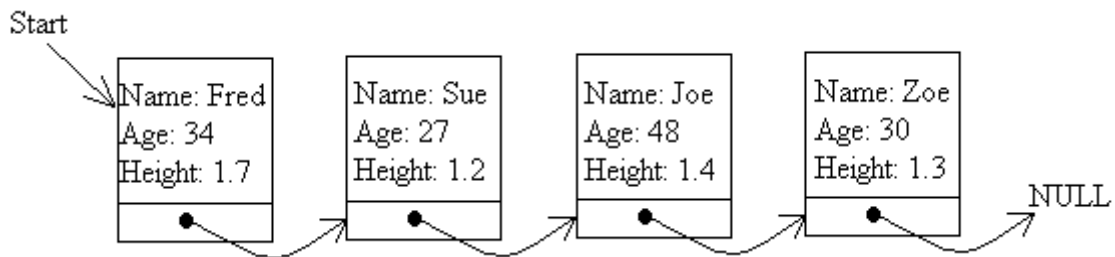
**Target:** You learn what linked lists are and how to handle them. Beside you repeat pointers and dynamic data object management.

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**1. What is a linked list?**

A linked list is a data structure which is built from structures and pointers. It forms a chain of "nodes" with pointers representing the links of the chain and holding the entire thing together. A linked list can be represented by a diagram like this one:



This linked list has four nodes in it, each with a link to the next node in the series. The last node has a link to the special value NULL. The NULL pointer has been presented in the lecture and is used here, to show that it is the last link in the chain. There is also another special pointer, called Start or Root, which points to the first link in the chain so that we can keep track of it.



Can you think at two situations where you would use linked lists:

- 1) .....
- 2) .....

## 2. Defining the data structure for a linked list

The key part of a linked list is a structure, which holds the data for each node (the name, address, age or whatever for the items in the list), and, most importantly, a pointer to the next node. Here I have given the structure of a typical node:

```
struct Node
{
    char name[20];           // Name of up to 20 letters
    int age;                 // D.O.B. would be better
    float height;           // In meters
    Node *next;             // Pointer to next node
};
Node *start_ptr = NULL;    // Start Pointer (root)
```

The important part of the structure is the line before the closing curly brackets. This gives a pointer to the next node in the list. This is the only case in C++ where you are allowed to refer to a data type (in this case `Node`) before you have even finished defining it!

I have also declared a pointer called `start_ptr` which will permanently point to the start of the list. To start with, there are no nodes in the list, which is why `start_ptr` is set to `NULL`.



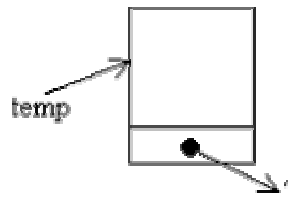
A library wants to manage its books with a computer program. A book is characterized by the author, the title and the ISBN number. Write down a useful node struct for this case.

## 3. Adding a node to the end of the list

The first problem that we face is how to add a node to the list. For simplicity's sake, we will assume that it has to be added to the end of the list, although it could be added anywhere in the list (a problem I will deal with later on).

Firstly, we declare the space for a pointer item and assign a temporary pointer to it. This is done using the `new` statement as follows:

```
Node *temp;
temp = new Node;
```



We can refer to the new node as `*temp`, i.e. "the node that `temp` points to". Having declared the node, we ask the user to fill in the details of the person, i.e. the name, age, address or whatever:

```
cout << "Please enter the name of the person: ";
cin >> temp->name;
cout << "Please enter the age of the person : ";
cin >> temp->age;
cout << "Please enter the height of the person : ";
cin >> temp->height;
temp->next = NULL;
```

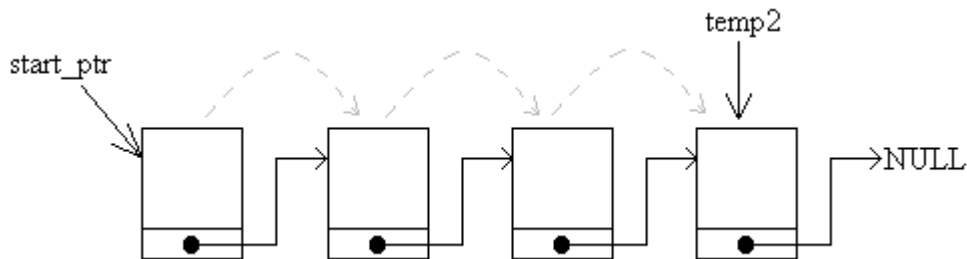
The last line sets the pointer from this node to the next to `NULL`, indicating that this node, when it is inserted in the list, will be the last node. Having set up the information, we have to decide what to do with the pointers.

Of course, if the list is empty to start with, there's no problem - just set the Start pointer to point to the new node (i.e. set it to the same value as `temp`):



Write down a code snippet doing the described task above. Don't forget to check if the list is empty. *Hint: 2 Lines should be enough.*

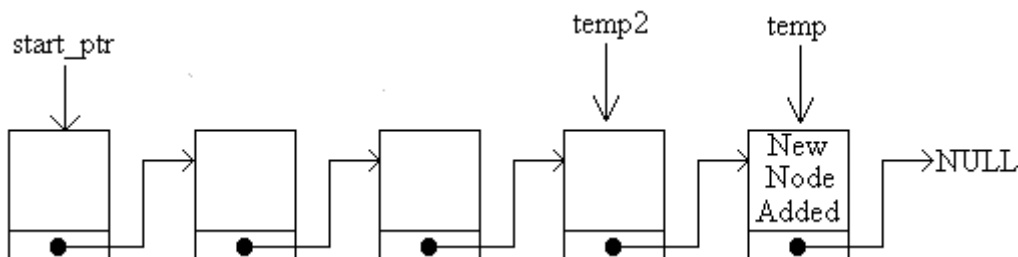
It is harder if there are already nodes in the list. In this case, the secret is to declare a second pointer, `temp2`, to step through the list until it finds the last node.



```
Node *temp2;
temp2 = start_ptr;           // We know temp2 is not NULL - list not
empty!
while (temp2->next != NULL)
    temp2 = temp2->next;    // Move to next link in chain
```

The loop will terminate when `temp2` points to the last node in the chain, and it knows when this happened because the `next` pointer in that node will point to `NULL`. When it has found it, it sets the pointer from that last node to point to the node we have just declared:

```
temp2->next = temp;
```



The link `temp2->next` in this diagram is the link joining the last two nodes.

The full code for adding a node at the end of the list is shown below, in its own little function:

```
void add_node_at_end ()
{
    node *temp, *temp2;           // Temporary pointers

    // Reserve space for new node and fill it with data
    temp = new node;
    cout << "Please enter the name of the person: ";
    cin >> temp->name;
    cout << "Please enter the age of the person : ";
    cin >> temp->age;
    cout << "Please enter the height of the person : ";
    cin >> temp->height;
    temp->next = NULL;

    // Set up link to this node
    if (start_ptr == NULL)
        start_ptr = temp;
    else
    {
        temp2 = start_ptr;       // We know this is not NULL - list not empty!
        while (temp2->next != NULL)
            temp2 = temp2->next; // Move to next link in chain
        temp2->next = temp;
    }
}
```



*(Optional)* If this was too easy till now. Assume that our linked list is sorted by age. So if we add a new node, we have to put it at the right position in the list. Adapted the above code dealing with this new requirement.

## 4. Displaying the list of nodes

Having added one or more nodes, we need to display the list of nodes on the screen. This is comparatively easy to do. You just have to traverse the whole list as we learned it in the previous part. Here is again a summary of the method:

1. Set a temporary pointer to point to the same thing as the start pointer.
2. If the pointer points to NULL, display the message "End of list" and stop.
3. Otherwise, display the details of the node pointed to by the start pointer.
4. Make the temporary pointer point to the same thing as the next pointer of the node it is currently indicating.
5. Jump back to step 2.

The temporary pointer moves along the list, displaying the details of the nodes it comes across. At each stage, it can get hold of the next node in the list by using the next pointer of the node it is currently pointing to.



Complete the following code snippet to print out the content of the linked list.  
*Hint: It might help if you draw a diagram of a linked list. If you have absolutely no idea how to manage this, study again at the procedure `add_node_at_end` from last chapter.*

```
Node *temp;  
temp = start_ptr;
```

```
// Display details for what temp points to  
cout << "Name : " << temp->name << endl;  
cout << "Age : " << temp->age << endl;  
cout << "Height : " << temp->height << endl;  
cout << endl;
```

## 5. Deleting a node from the list

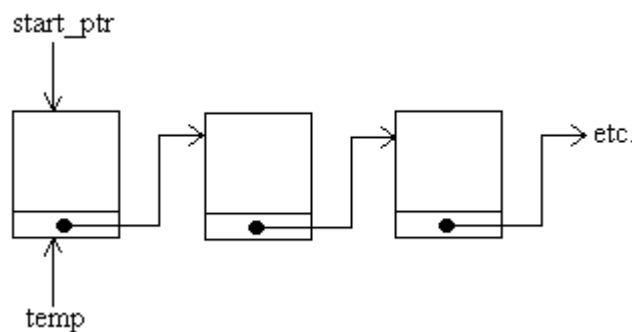
When it comes to deleting nodes, we have three choices: Delete a node from the start of the list, delete one from the end of the list, or delete one from somewhere in the middle. For simplicity, I shall just deal with deleting one from the start or from the end - I shall put off the evil day when I have to explain how to delete one from the middle (by then, I might have worked out how to do it!)

When a node is deleted, the space that it took up should be reclaimed. Otherwise the computer will eventually run out of memory space. This is done with the delete instruction:

```
delete temp; // Release the memory pointed to by temp
```

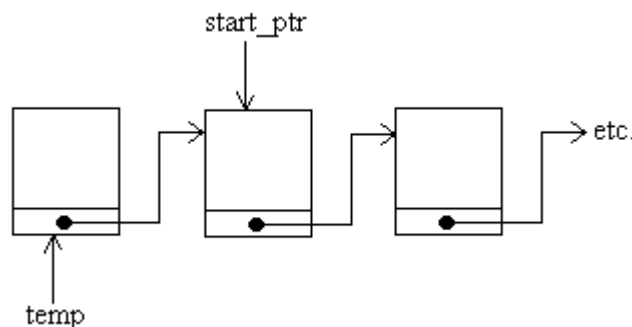
However, we can't just delete the nodes willy-nilly as it would break the chain. We need to reassign the pointers and then delete the node at the last moment. Here is how we go about deleting the first node in the linked list:

```
Node *temp;  
temp = start_ptr; // Make the temporary pointer  
                // identical to the start pointer
```

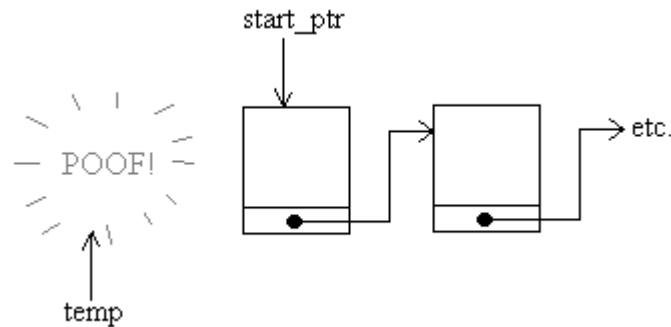


Now that the first node has been safely tagged (so that we can refer to it even when the start pointer has been reassigned), we can move the start pointer to the next node in the chain:

```
start_ptr = start_ptr->next; // Second node in chain.
```



```
delete temp; // Wipe out original start node
```



Here is the function that deletes a node from the start:

```
void delete_start_node()
{
    Node *temp;
    temp = start_ptr;
    start_ptr = start_ptr->next;
    delete temp;
}
```

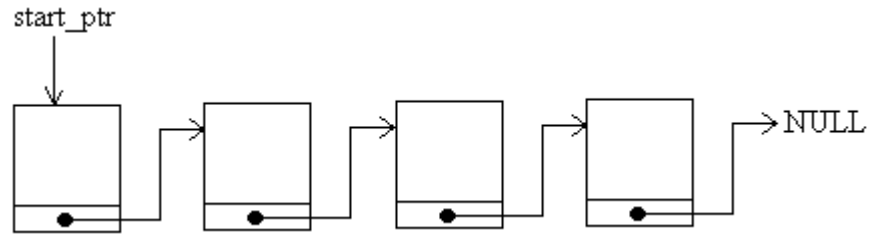
Deleting a node from the end of the list is not much harder, as the temporary pointer must find where the end of the list is by hopping along from the start. This is done using code that is almost identical to that used to insert a node at the end of the list. But it is necessary to maintain two temporary pointers, `temp1` and `temp2`. The pointer `temp1` will point to the last node in the list and `temp2` will point to the previous node. We have to keep track of both as it is necessary to delete the last node and immediately afterwards, to set the `next` pointer of the previous node to `NULL` (it is now the new last node).

1. Look at the start pointer. If it is `NULL`, then the list is empty, so print out a "No nodes to delete" message.
2. Make `temp1` point to whatever the start pointer is pointing to.
3. If the `next` pointer of what `temp1` indicates is `NULL`, then we've found the last node of the list, so jump to step 7.
4. Make another pointer, `temp2`, point to the current node in the list (where `temp1` is pointing to).
5. Make `temp1` point to the next item in the list.
6. Go to step 3.
7. If you get this far, then the temporary pointer, `temp1`, should point to the last item in the list and the other temporary pointer, `temp2`, should point to the last-but-one item.
8. Delete the node pointed to by `temp1`.
9. Mark the `next` pointer of the node pointed to by `temp2` as `NULL` - it is the new last node.

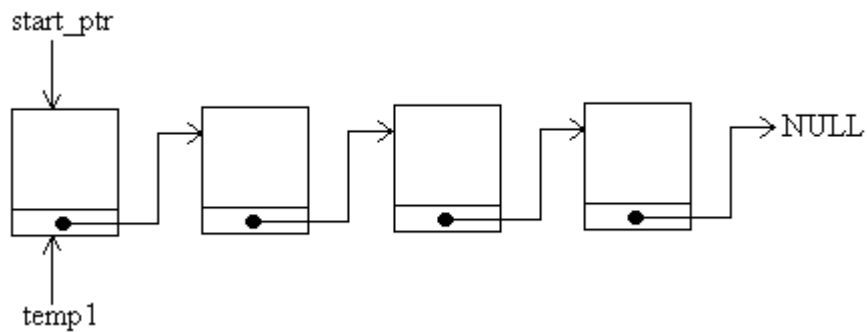


Every thing clear? No? So let's try it with a rough drawing. This is always a good idea when you are trying to understand an abstract data type. But in some of the following drawings marked with the hand the `temp1` and `temp2` pointers disappeared. Fix them.

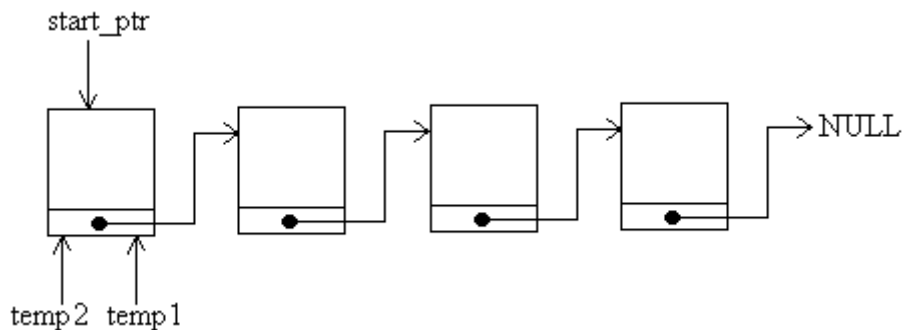
Suppose we want to delete the last node from this list:



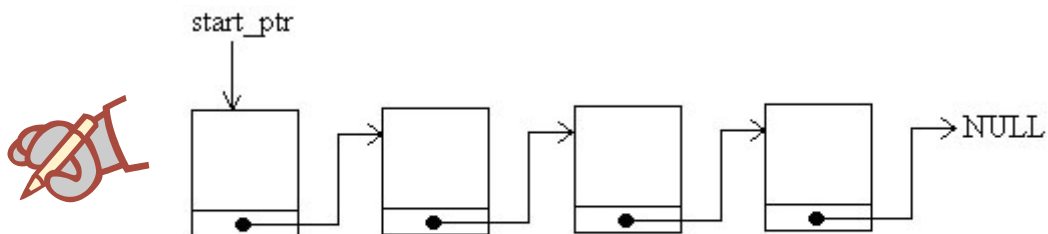
Firstly, the start pointer doesn't point to NULL, so we don't have to display a "Empty list, wise guy!" message. Let's get straight on with step2 - set the pointer `temp1` to the same as the start pointer:



The next pointer from this node isn't NULL, so we haven't found the end node. Instead, we set the pointer `temp2` to the same node as `temp1`

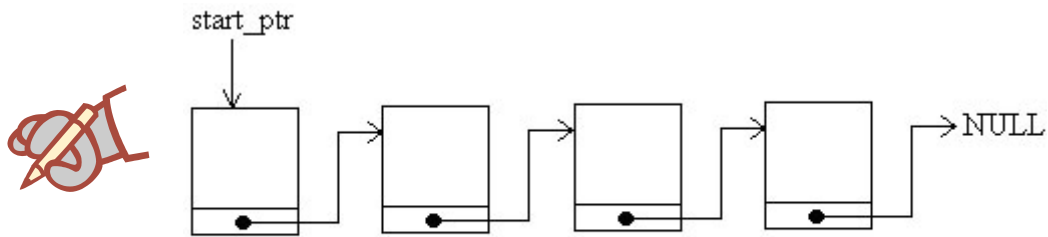


and then move `temp1` to the next node in the list:

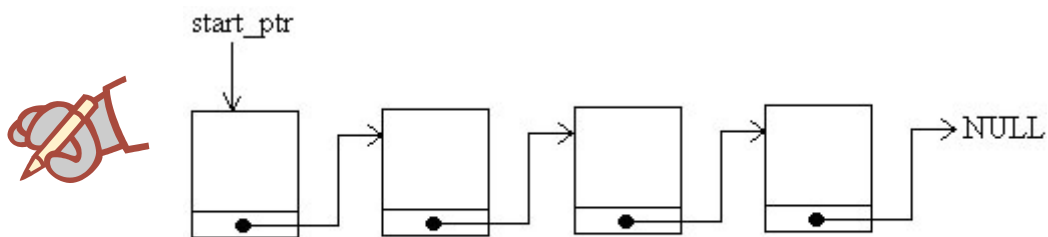




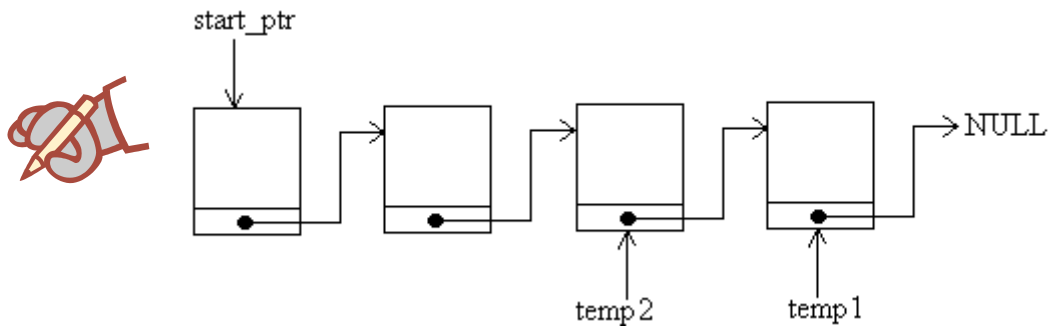
Going back to step 3, we see that `temp1` still doesn't point to the last node in the list, so we make `temp2` point to what `temp1` points to



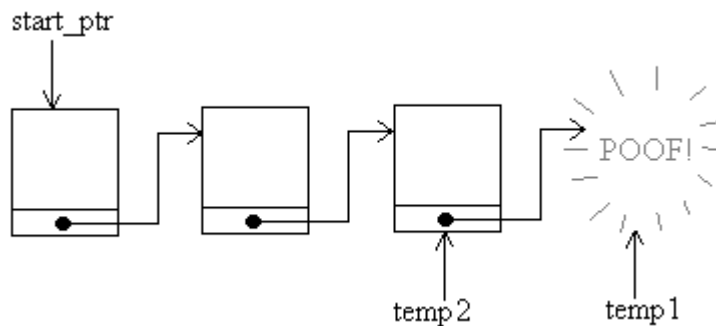
and `temp1` is made to point to the next node along:



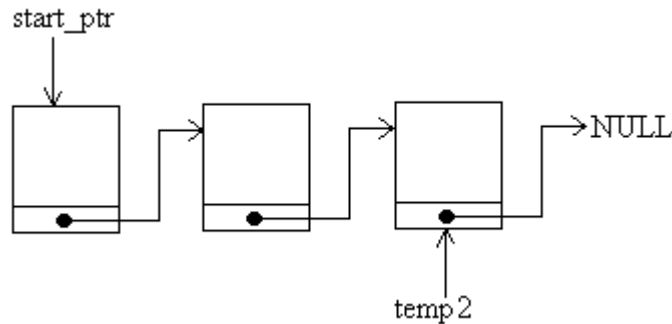
Eventually, this goes on until `temp1` really is pointing to the last node in the list, with `temp2` pointing to the penultimate node:



Now we have reached step 8. The next thing to do is to delete the node pointed to by `temp1`



and set the next pointer of what `temp2` indicates to `NULL`:



I suppose you want some code for all that! All right then ....

```

void delete_end_node()
{
    Node *temp1, *temp2;
    if (start_ptr == NULL)
        cout << "The list is empty!" << endl;
    else
    {
        temp1 = start_ptr;
        while (temp1->next != NULL)
        {
            temp2 = temp1;
            temp1 = temp1->next;
        }
        delete temp1;
        temp2->next = NULL;
    }
}
  
```

The code seems a lot shorter than the explanation!



Let's have a profound look at the code above. Can you spot a problem?

.....

Now, the sharp-witted amongst you will have spotted a problem. If the list only contains one node, the code above will malfunction. This is because the function goes as far as the `temp1 = start_ptr` statement, but never gets as far as setting up `temp2`. The code above has to be adapted so that if the first node is also the last (has a `NULL` next pointer), then it is deleted and the `start_ptr` pointer is assigned to `NULL`. In this case, there is no need for the pointer `temp2`.



I already prepared a new code snippet for you catching this problem. But it still lacks of some lines handling the critical situation. Try to fixe them.

```
void delete_end_node()
{
    node *temp1, *temp2;
    if (start_ptr == NULL)
        cout << "The list is empty!" << endl;
    else
    {
        temp1 = start_ptr;
        if (temp1->next == NULL)           // This part is new!
        {

                                                    // Here comes your code
                                                    // Fix me!

        }
    }
    else
    {
        while (temp1->next != NULL)
        {
            temp2 = temp1;
            temp1 = temp1->next;
        }
        delete temp1;
        temp2->next = NULL;
    }
}
}
```



*(Optional)* If this was very boring and too easy for you I have an expert task for you. Try to adapt the above code to delete all nodes with a certain age.

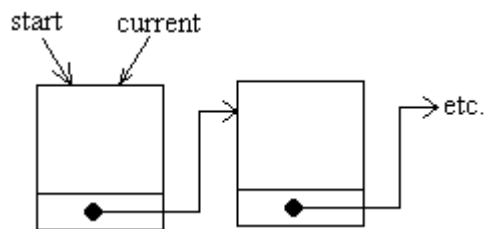
## 6. Navigating through the list

One thing you may need to do is to navigate through the list, with a pointer that moves backwards and forwards through the list, like an index pointer in an array. This is certainly necessary when you want to insert or delete a node from somewhere inside the list, as you will need to specify the position.

I will call the mobile pointer `current`. First of all, it is declared, and set to the same value as the `start_ptr` pointer:

```
Node *current;
current = start_ptr;
```

Notice that you don't need to set `current` equal to the address of the start pointer, as they are both pointers. The statement above makes them both point to the same thing:



It's easy to get the `current` pointer to point to the next node in the list (i.e. move from left to right along the list). If you want to move `current` along one node, use the `next` field of the node that it is pointing to at the moment:

```
current = current->next;
```

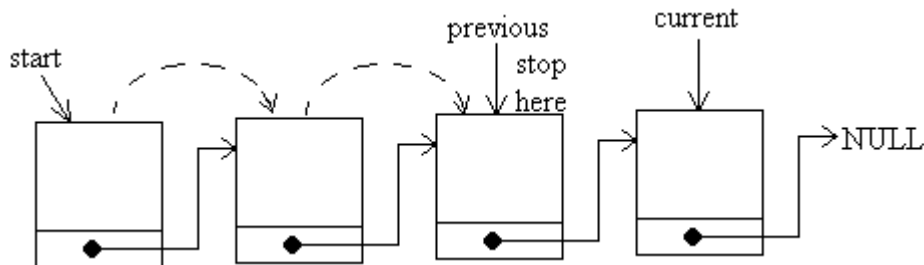
In fact, we had better check that it isn't pointing to the last item in the list. If it is, then there is no next node to move to:



Fix the if condition below.

```
if (.....)
    cout << "You are at the end of the list." << endl;
else
    current = current->next;
```

Moving the current pointer back one step is a little harder. This is because we have no way of moving back a step automatically from the current node. The only way to find the node before the current one is to start at the beginning, work our way through and stop when we find the node before the one we are considering the moment. We can tell when this happens, as the next pointer from that node will point to exactly the same place in memory as the current pointer (i.e. the current node).



First of all, we had better check to see if the current node is also first the one. If it is, then there is no "previous" node to point to. If not, check through all the nodes in turn until we detect that we are just behind the current one (Like a pantomime - "behind you!")

```
if (current == start_ptr)
    cout << "You are at the start of the list" << endl;
else
{
    node *previous; // Declare the pointer
    previous = start_ptr;
    while (previous->next != current)
        previous = previous->next;
    current = previous;
}
```

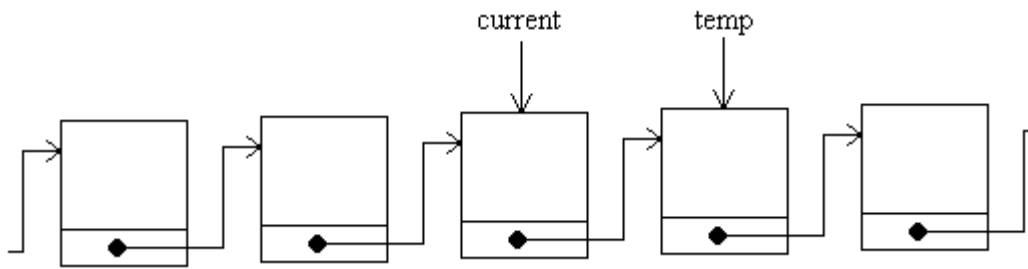
The else clause translates as follows: Declare a temporary pointer (for use in this else clause only). Set it equal to the start pointer. All the time that it is not pointing to the node before the current node, move it along the line. Once the previous node has been found, the current pointer is set to that node - i.e. it moves back along the list.

Now that you have the facility to move back and forth, you need to do something with it. Firstly, let's see if we can alter the details for that particular node in the list:

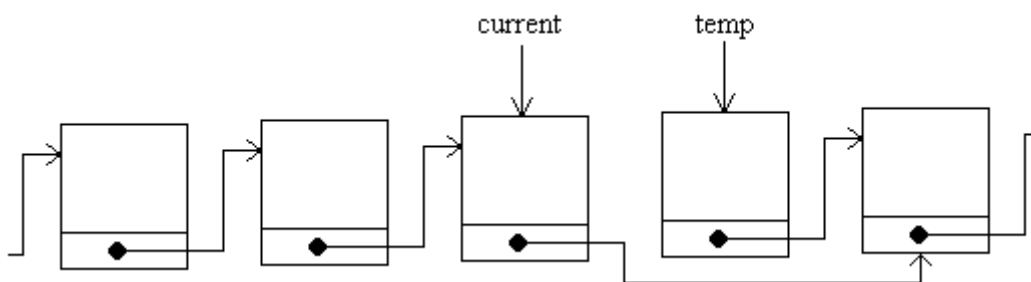
```
cout << "Please enter the new name of the person: ";
cin >> current->name;
cout << "Please enter the new age of the person : ";
cin >> current->age;
cout << "Please enter the new height of the person : ";
cin >> current->height;
```

The next easiest thing to do is to delete a node from the list directly after the current position. We have to use a temporary pointer to point to the node to be deleted. Once this node has been "anchored", the pointers to the remaining nodes can be readjusted before the node on death row is deleted. Here is the sequence of actions:

Firstly, the temporary pointer is assigned to the node after the current one. This is the node to be deleted:



Now the pointer from the current node is made to leap-frog the next node and point to the one after that:



The last step is to delete the node pointed to by temp.

Here is the code for deleting the node. It includes a test at the start to test whether the current node is the last one in the list:

```
if (current->next == NULL)
    cout << "There is no node after current" << endl;
else
{
    node *temp;
    temp = current->next;
    current->next = temp->next;    // Could be NULL
    delete temp;
}
```

Adding a node after the current one is done very similarly, but I haven't illustrated it with diagrams.



Develop the code to add a node after the current one.

## 7. Double Linked Lists

There is also another possibility how you can traverse back- and forward through linked list. But for this we have to adapt our node struct to a double linked list. The idea is very easy. You add another pointer to each node linking to the previous node. The pointer of the first node is set to NULL similarly as the next pointer of the last node.

```
struct Node
{
    char name[20];    // Name of up to 20 letters
    int age;         // D.O.B. would be better
    float height;   // In meters
    Node *next;     // Pointer to next node
    Node *previous; // Pointer to previous node
};
```



Illustrate a double linked list as we did it with common linked lists.



*(Optional)* If this whole paper was very boring for you, I have an extra killer task for you. Write down code snippets for adding and deleting nodes from a double linked list at any position, e.g. by name. But be very careful, there are many special cases you have to think at.

## 8. and so on ...

By now, we have a fair number of routines for setting up and manipulating a linked list. What you should do now is string them altogether to form a coherent program. In exercise number 11 you will have the chance to use Linked Lists for your Club Search Pro program.

Here are some other routines that you might like to write and include in your program:

- Deleting the current node in the list.
- Saving the contents of a linked list to a file.
- Loading the contents of a linked list from a file and reconstructing it.
- Sorting the contents of a linked list.