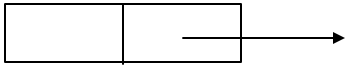
Recursive Data Representations

We can define structures with pointer fields that refer to the structure type containing them.

```
struct list {
   int data;
   struct list *next;
}
```

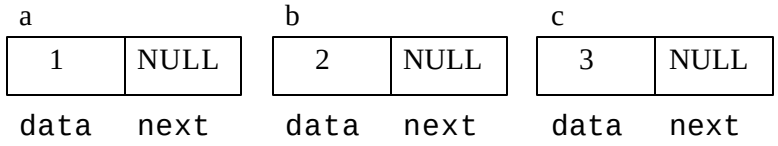


data **next**

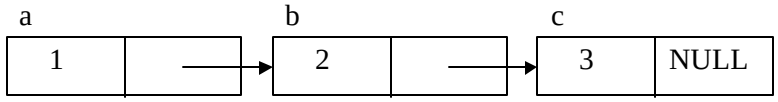
The pointer variable `next` is called a *link*. Each structure is linked to a succeeding structure by way of the field `next`. The pointer variable `next` contains an address of either the location in memory of the successor `struct list` element or the special value `NULL`.

Example:

```
struct list a, b, c;

a.data = 1;
b.data = 2;
c.data = 3;
a.next = b.next = c.next = NULL;
```




```
a.next = &b;
b.next = &c;
```



`a.next->data` has value `2`
`a.next->next->data` has value `3`

`b.next->next->data` error !!

Static and Dynamic Variables

- Static Variables:

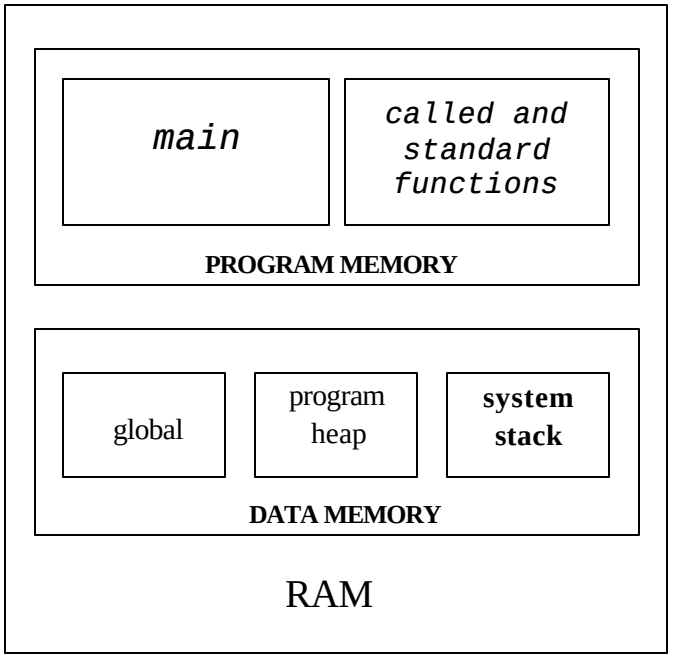
– They are created during compilation. (Fixed memory is reserved for them.)
– They cannot be allocated/deallocated during the execution of the program.
– Names are associated with them.

```
int x;
char y[10];
int z[100];
```

- Dynamic Variables:

– They are created (allocated) and deallocated during the execution of the program.
– no names are associated with them. The only way to access them is to use pointers.
– They don't exist during compilation. Once they are created they contain data and must have a type like any other variable. Thus we can talk about creating a new dynamic variable of type *x* and setting a pointer to point to it, or returning a dynamic variable of type *x* to the system (deallocation).

A Conceptual View of Memory



Dynamic Data

For example:

- We must maintain a list of data
- At some moments, the list is small, so we want to use only a little memory

- At other moments, the list is larger, so we need to use more memory

- Declaring variables in the standard way won't work here because we *don't know how many* variables to declare
- We need a way to *allocate* and *deallocate* data *dynamically* (i.e., *on the fly)*

Dynamic Memory Allocation

Creating and maintaining dynamic data structures requires dynamic memory allocation – the ability for a program to obtain more memory space at execution time to hold new values, and to release space no longer needed.

In C, functions `malloc` and `free`, and operator `sizeof` are essential to dynamic memory allocation.

- Unary operator `sizeof` is used to determine the size in bytes of any data type.

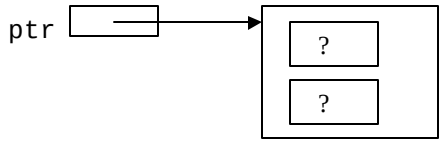
  e.g.

  ```
  sizeof(double)
  sizeof(int)
  ```

- Function `malloc` takes as an argument the number of bytes to be allocated and return a pointer of type `void *` to the allocated memory. (A `void *` pointer may be assigned to a variable of any pointer type.) It is normally used with the `sizeof` operator.

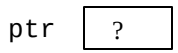
Example:

```
struct node{
   int data;
   struct node *next;
};

struct node *ptr;

ptr = (struct node *)    /*type casting */
       malloc(sizeof(struct node));
```



- Function `free` deallocates memory- i.e. the memory is returned to the system so that the memory can be reallocated in the future.
  e.g.

```
free(ptr);
```



Linked Lists

- It is an important data structure.
- An abstraction of a list: i.e. a sequence of nodes in which each node is linked to the node following it.
- Lists of data can be stored in arrays, but linked lists provide several advantages:

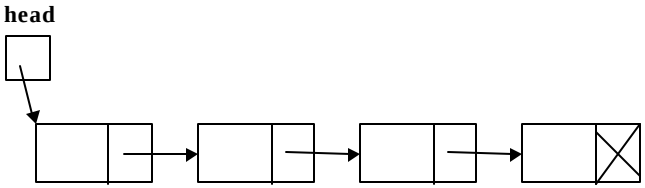
Arrays

– In an array each node (element) follows the previous one physically (i.e. contiguous spaces in the memory)
– Arrays are fixed size: either too big (unused space or not big enough (overflow problem)
– Maximum size of the array must be predicted which is sometimes impossible.
– Inserting and deleting elements into an array is difficult.

Linked Lists

– Linked lists are appropriate when the number of data elements to be represented in the data structure at once is unpredictable.
– Linked lists are dynamic, so the length of a list can increase or decrease as necessary.
– Each node does not necessarily follow the previous one physically in the memory.
– Linked lists can be maintained in sorted order by inserting or deleting an element at the proper point in the list.

Simple Linked List



- The head pointer addresses the first node of the list, and each node points at a successor node. The last node has a link value NULL.

Empty List

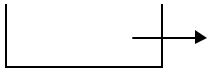
Empty Linked list is a single pointer having the value of NULL.

```
head = NULL;
```

Nodes

A node in a linked list is a structure that has at least two fields. One of the fields is a data field; the other is a pointer that contains the address of the next node in the sequence.

A node with one data field:



```
number link
```

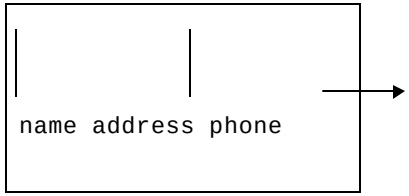
```
struct node{
    int number;
    struct node * link;
};
```

A node with 3 data fields:

```
name id grdPtsnext_student
```

```
struct student{
     char name[20];
     int id;
     double grdPts;
     struct student
          *next_student;
};
```

A structure in a node:




```
data        next
```

```
struct person{
    char name[20];
    char address[30];
    char phone[10];
};

struct person_node{
    struct person data;
    struct person_node
           *next;
};
```

Basic Linked List Operations

1. Add a node
2. Delete a node
3. Looking up a node
4. List Traversal (e.g. Counting nodes)

Add a Node

There are four steps to add a node to a linked list:

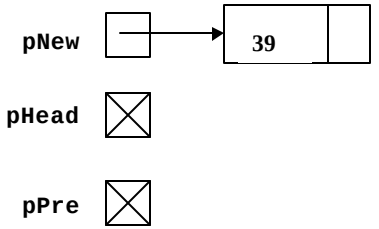
1. Allocate memory for the new node.
2. Determine the insertion point (you need to know only the new node's predecessor (`pPre`)
3. Point the new node to its successor.
4. Point the predecessor to the new node.

Pointer to the predecessor (`pPre`) can be in one of two states:

- it can contain the address of a node (i.e. you are adding somewhere after the first node – in the middle or at the end)
- it can be NULL (i.e. you are adding either to an empty list or at the beginning of the list)

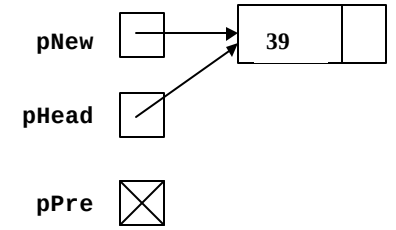
Adding to Empty List

BEFORE



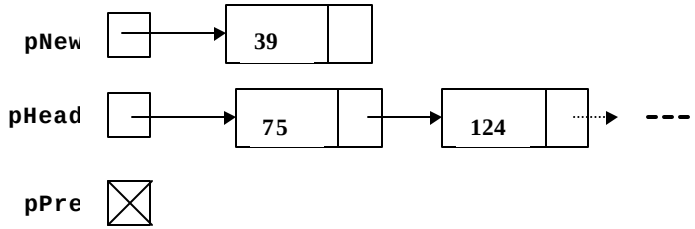

```
pNew->next = pHead;   // set link to NULL
pHead = pNew;      // point list to first node
```

AFTER



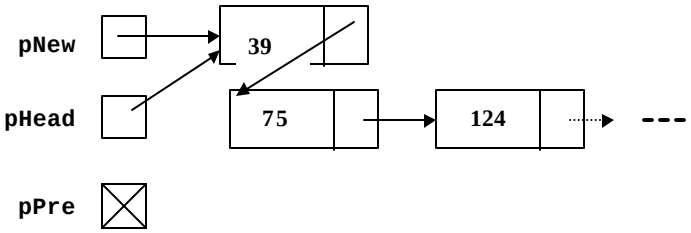
Add Node at Beginning

BEFORE



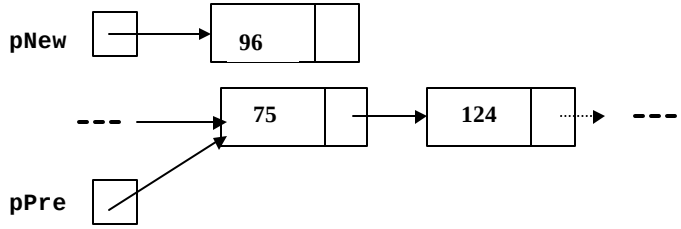

```
// Same code
pNew->next = pHead;
pHead = pNew;
```

AFTER



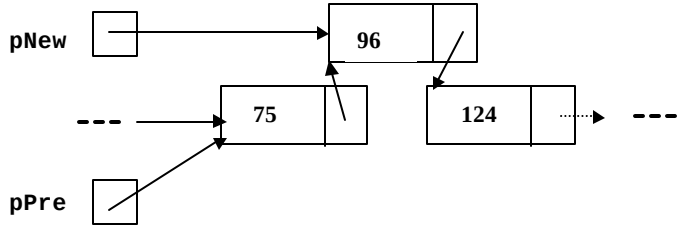
Add Node in Middle

BEFORE



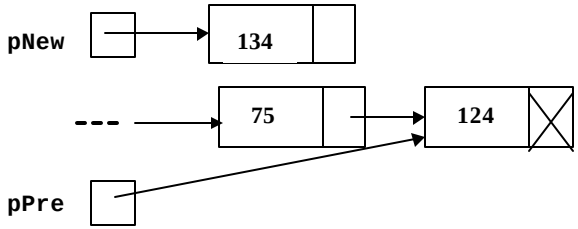

```
pNew->next = pPre->next;
pPre->next = pNew;
```

AFTER



Add Node at End

BEFORE

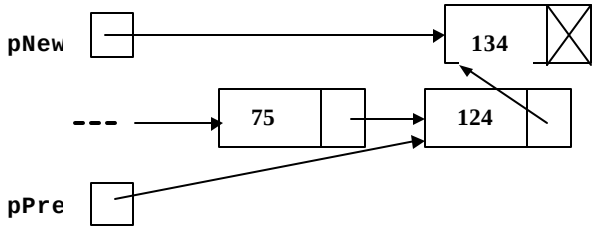



```
pNew->next = NULL;
pPre->next = pNew;
```

OR:

```
// Same as the code for adding a node in the
middle
pNew->next = pPre->next;
pPre->next = pNew;
```

AFTER



Inserting a Node to a Linked List

Given the head pointer (`pHead`), the predecessor (`pPre`) and the data to be inserted (`item`), we must allocate memory for the new node (`pNew`) and adjust the link pointers.

```
// Insert a node into a linked list

   struct node *pNew;

   pNew =(struct node *) malloc(sizeof(struct
                                        node));

   pNew->data = item;

   if (pPre == NULL){
   //Adding before first node or to empty list
       pNew->next = pHead;
       pHead = pNew;
   }
   else {
      // Adding in middle or at end
      pNew->next = pPre->next;
      pPre->next = pNew;
   }
```

Delete a Node

Deleting a node requires that we logically remove the node from the list by changing various link pointers and then physically deleting the node from the heap.

We can delete

- the first node
- any node in the middle
- the end node

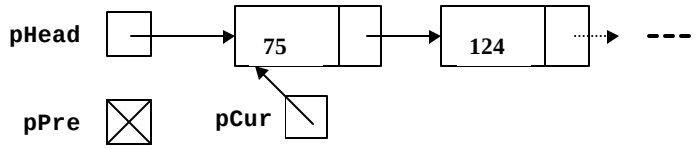
To logically delete a node:

1. first locate the node itself (`pCur`) and its predecessor (`pPre`)
2. change its predecessor's link field to point to the deleted node's successor.
3. recycle the node using free.

Note: We may be deleting the only node in a list. This will result in an empty list in which case the head pointer is set to NULL.

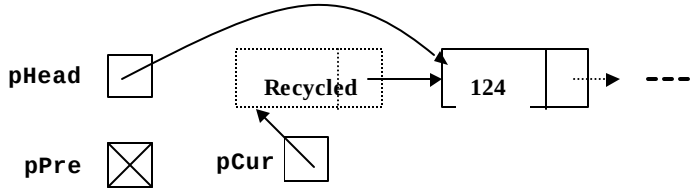
Delete First Node

BEFORE



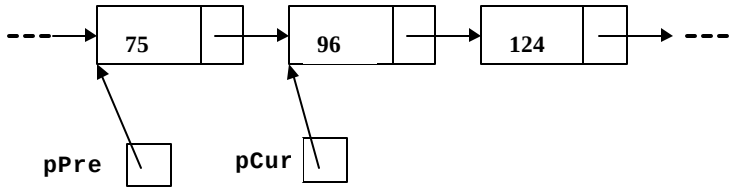

```
pHead = pCur -> next;
free (pCur);
```

AFTER



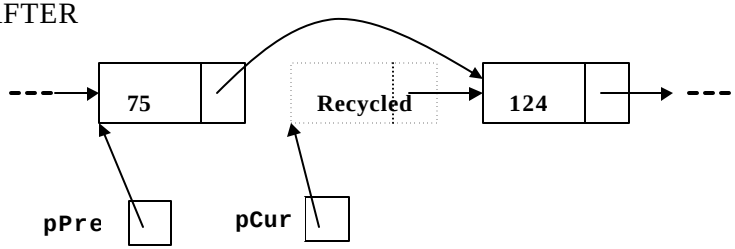
General Delete Case

BEFORE




```
pPre->next = pCur->next;
free(pCur);
```

AFTER



Deleting a node

Given a pointer to the head of the list, the node to be deleted, and the delete node's predecessor, we delete the node and recycle its memory.

```
// Delete a node from a linked list
   if (pPre == NULL)
      // Deleting first node
      pHead = pCur->next;
   else
      // Deleting other nodes
      pPre->next = pCur ->next;

   free(pCur);
```

Search Linked List

Both insert and delete operations have to search the linked list.

- To add a node, we must identify the logical predecessor of the new node.
- To delete a node, we must identify the location of the node to be deleted and its logical predecessor.

Basic Search Concept

Given a target value, the search attempts to locate the requested node in the linked list. If a node in the list matches the target value, the search return true; otherwise it returns false.

```
// Search nodes in a linked list
pPre = NULL;
pCur = pHead;

// Search until target is found or we reach
// the end of list
while (pCur != NULL && pCur->data != target){
   pPre = pCur;
   pCur = pCur->next;
}

//Determine if target is found

if (pCur)
   found = 1;
else
   found = 0;
```


Traversing Linked Lists

List traversal requires that all of the data in the list be processed.

```
// Traverse a linked list

struct node *pWalker;

pWalker = pHead;
printf("List contains:\n");

while (pWalker){
   printf("%d ", pWalker->data);
   pWalker = pWalker ->next;
}
```