HUST

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HANOI UNIVERSITY OF SCIENCE AND TECHNOLOGY

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LINKED LIST (PART I)

IT3230E Data structure and algorithms Lab

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Outline

- **Introduction to linked list**
- Implementation of singly linked list data structure
- Using list in specific problems

Towards Dynamic Data Structures

- Array is a collection of homogeneous elements which are stored at consecutive locations

- Main limitations of arrays:
  - It is a static data structure
  - Its size must be known at compilation time, in most programming languages
  - Inefficient insertion and deletion of elements

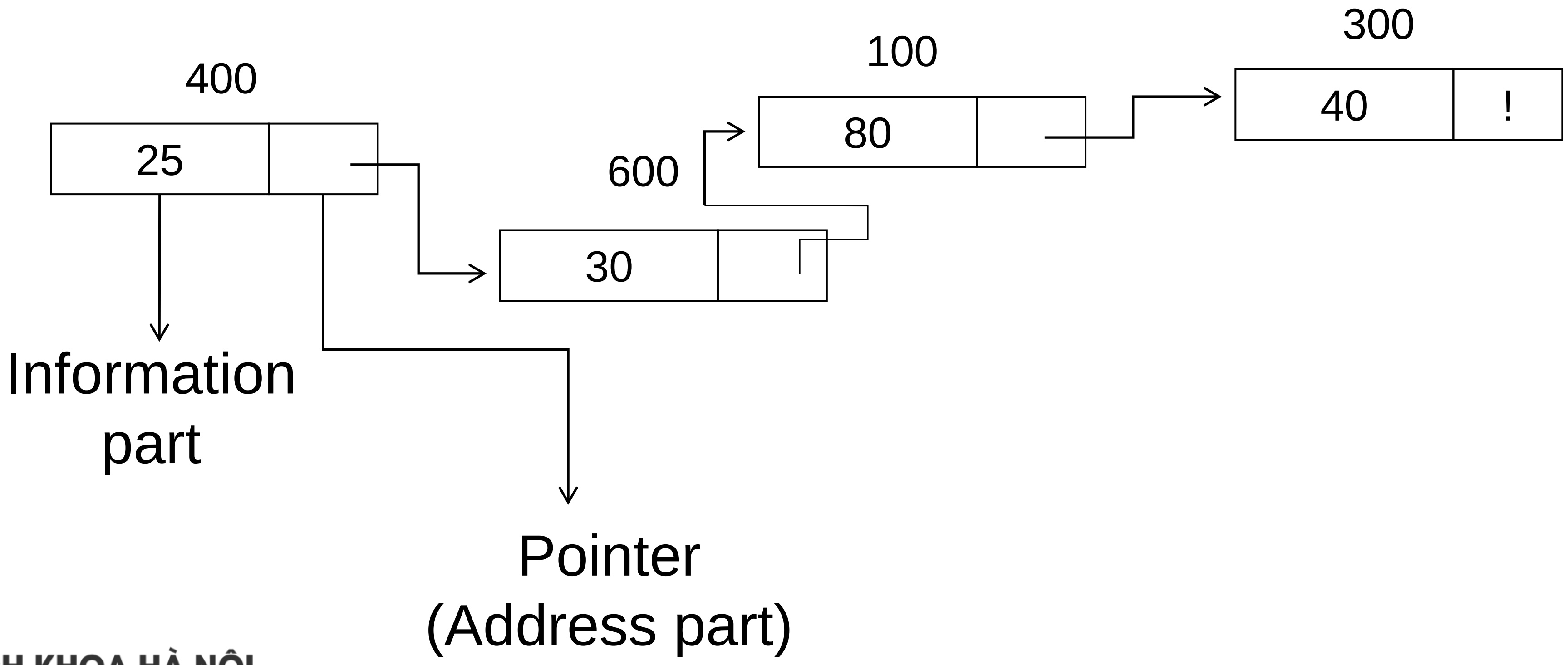
- A dynamic data structure can overcome these problems

What is a Dynamic Data Structure?

- A data structure that can shrink or grow during program execution
- The size of a dynamic data structure is not necessarily known at compilation time, in most programming languages
- Efficient insertion and deletion of elements
- The data in a dynamic data structure can be stored in non-contiguous (arbitrary) locations
- Linked list is an example of a dynamic data structure

What is a singly linked List?

- A linked list is a collection of nodes, each element (node) holding some information and a pointer to the next node in the list
- In the following example, there are four nodes, which are not stored at consecutive locations

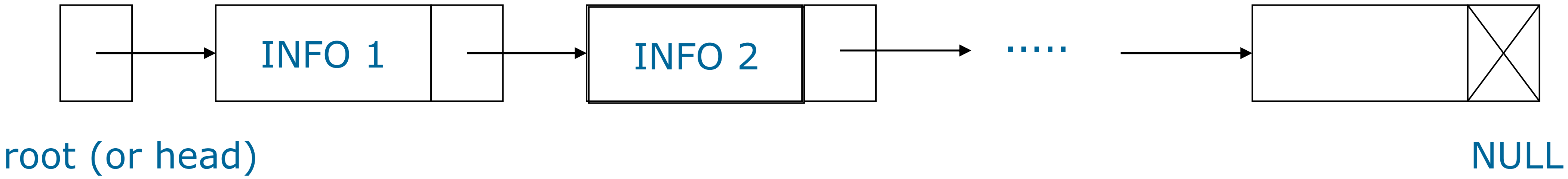


Outline

- Introduction to linked list
- **Implementation of singly linked list data structure**
- Using list in specific problems

Implementation of singly linked list in C

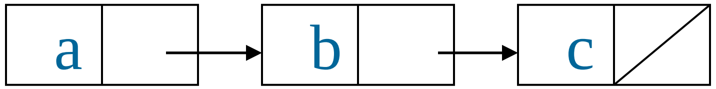
- In C, the pointer is used for the location of the next element.
  - the value of the last node is NULL
- Using Self-Referential Structures
  - You may define the type for INFO data using struct and typedef
- Important factor: root pointer
  - always points to the first element



Self-Referential Structures

- One or more of its components is a pointer to itself.

```
struct list {
char data;
struct list *link;
};
list item1, item2, item3;
item1.data=‘a’;
item2.data=‘b’;
item3.data=‘c’;
item1.link=item2.link=item3.link=NULL;
```



Operations for singly linked list

- Memory allocation for a new element (node)
- Insert new node to the list
  - at head
  - in the middle (based on position of current node or an absolute position):
    - after current node
    - before current node
- Delete (remove) an element
- Navigate (traverse) – Display the content - Searching
- Inverse the list
- Free the list
- …

Main steps in building a program using data structures

- Data types definition of the data structure
  - for an INFO field, for a data structure item
- Global variable declaration (optional)
  - important pointers for example
- Implementation of the useful operations on data structure as functions
- Usage of data structures and functions in the program

Illustrative Problem: Phone contact management

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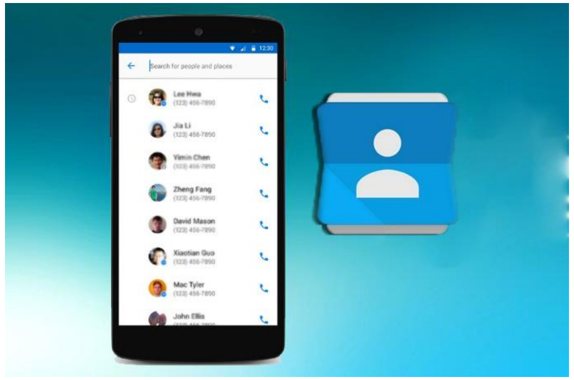
Description

- Develop a mobile phone contact management program, in which each contact includes information about full name, phone number and email.
- Build a single linked list to store and manage contacts with a set of functions that allow:
  - Add a new element to the beginning of the list.
  - Add a new element after the current contact element
  - Display stored contacts in the list
  - Delete a contact: At the top of the list; In the current position,..
  - Reverse the list - Free up memory allocated to the list



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Type declaration for INFO field in each node

- you can organize contact elements and data structure using following record structure **contact**. Define by your self a structure for storing information about an contact address.

```
typedef struct contact_t {
        char name[20];
        char tel[11];
        char email[25];
} contact; // contact is the type for INFO field
```

Declaration of singly linked list of contacts

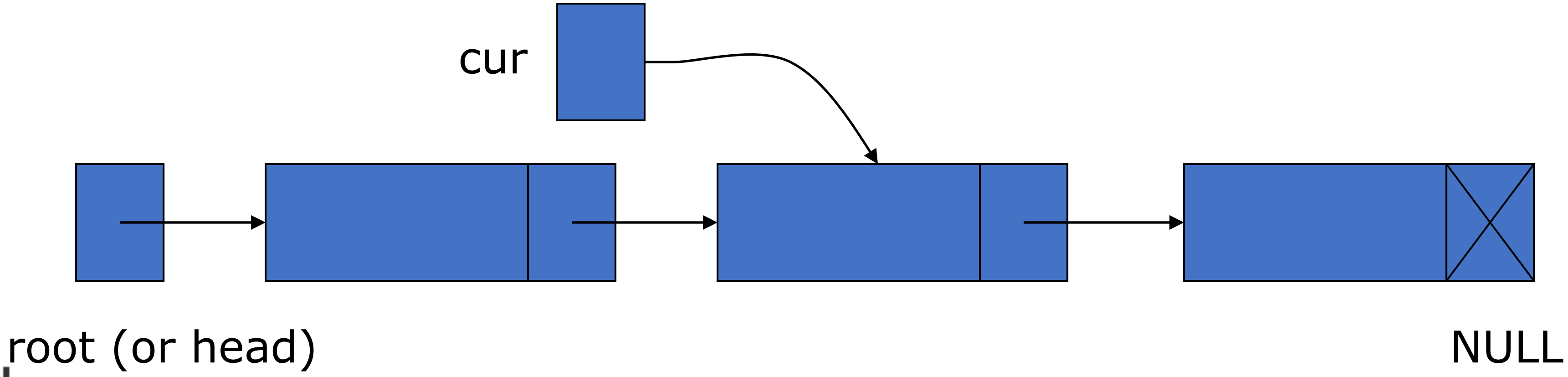
```
struct list_el {
contact el;
struct list_el *next;
};
typedef struct list_el node;
```

- “next” is the pointer variable which can express the next element; an element of the type node.
- “el” is the instance of a contact.

Declaration of important pointers

- root (or head) keeps the head of the list.
  - It is used to manage, get access to the list
- cur: Pointer variable that keeps the element just now.
- prev: Pointer point to the previous node of the one pointed by cur (optional)

```
node *root, *cur;
node *prev; /* in case you used prev */
```



Function implementation: memory allocation for a new node

```
node* makeNewNode(){
  node* new = (node*) malloc(sizeof(node));
  strcpy((new->el).name, "Tran Van Thanh");
  .... // similar statement for other contact fields
  new->next =NULL;
  return new;
}
```

- The function allocates memory and initializes one node but do not add it to the list
- Limitation: low reusability because value of data field is assigned directly in the code

Function implementation: memory allocation for a new node

- Improve the makeNewNode function
  - receive the data field as parameter - give a specific data (for the new node) ➔ allocate new node in the memory and return the pointer
  - higher reusability : For example, load data from a record file and create corresponding nodes

```
node* makeNewNode(contact ct){
  node* new = (node*)malloc(sizeof(node));
  new->el= ct;
  new->next =NULL;
  return new;
}
```

Getting input data for a node

```
contact readNode(){
    contact tmp;
    printf(“Input the full name:”);
    gets(tmp.name);
    ...
    return tmp;
}
```

Display the information of one node

- Write the function displaying the data inside a give node pointed by p.

```
void displayNode(node* p){
/* display name, tel, email in columns */


}
```

- **These functions (read node, display node) do not belong to the data structures but necessary and depend on problem.**

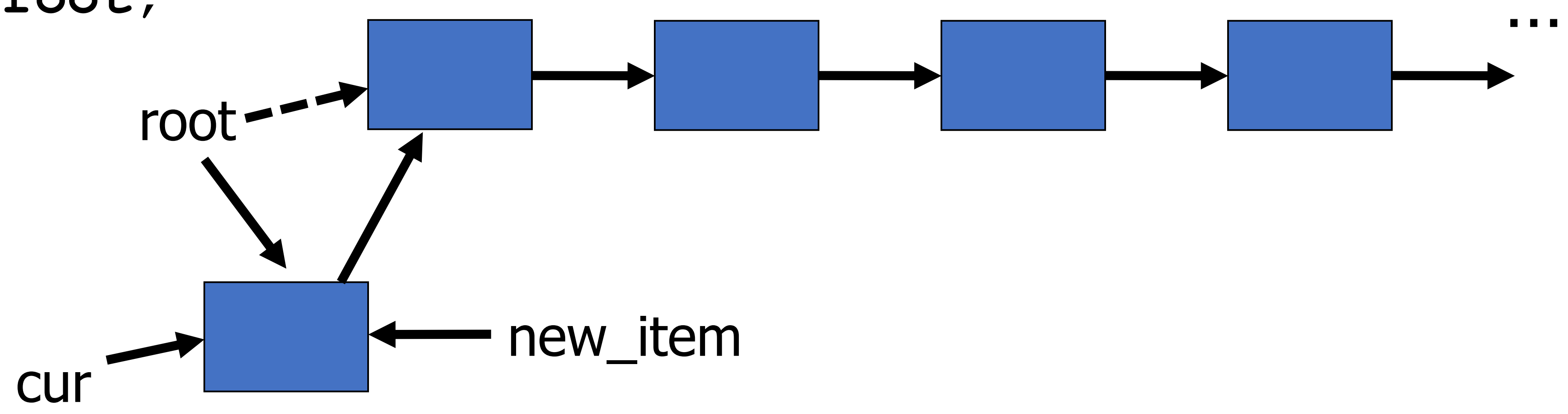
Display the information of one node - Solution

```
   void displayNode(node* p){
   if (p==NULL){printf(“NULL Pointer error.\n”); return; }
   contact tmp = p->el;
   printf(“%-20s\t%-15s\t%-25s%-p\n”, tmp.name, tmp.tel,
    tmp.email, p->next);
   }
//driver main function
void main(){
   contact tmp = readNode();
   root = makeNewNode(tmp);
   displayNode(root);
}
```

Insert a new node to the list : at head

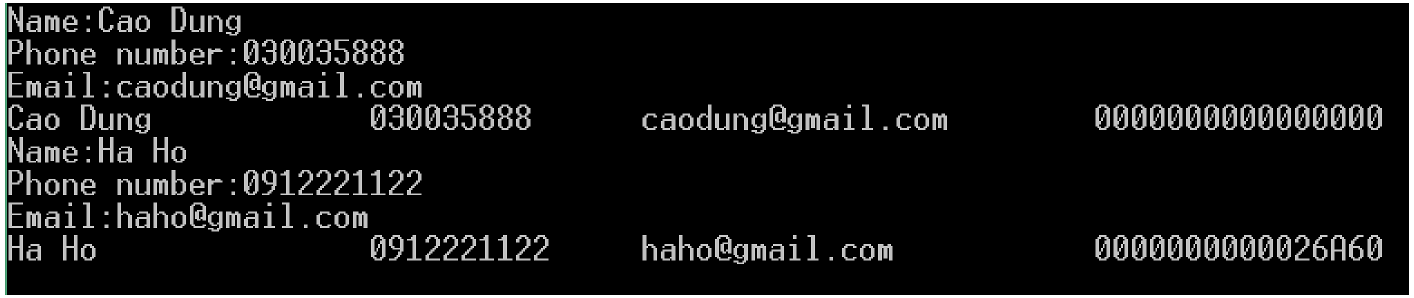
- Hint on logic:

```
create new_item
new->next = root;
root = new;
cur= root;
```



Insert node at head of the list : solution

```
void insertAtHead(contact ct){
  node* new = makeNewNode(ct);
  new->next = root;
  root = new;
  cur = root;
}
void main(){
  contact tmp; int i;
  for(i=0;i<2;i++){
      tmp = readNode(); insertAtHead(tmp);
      displayNode(root);
   }
}
```

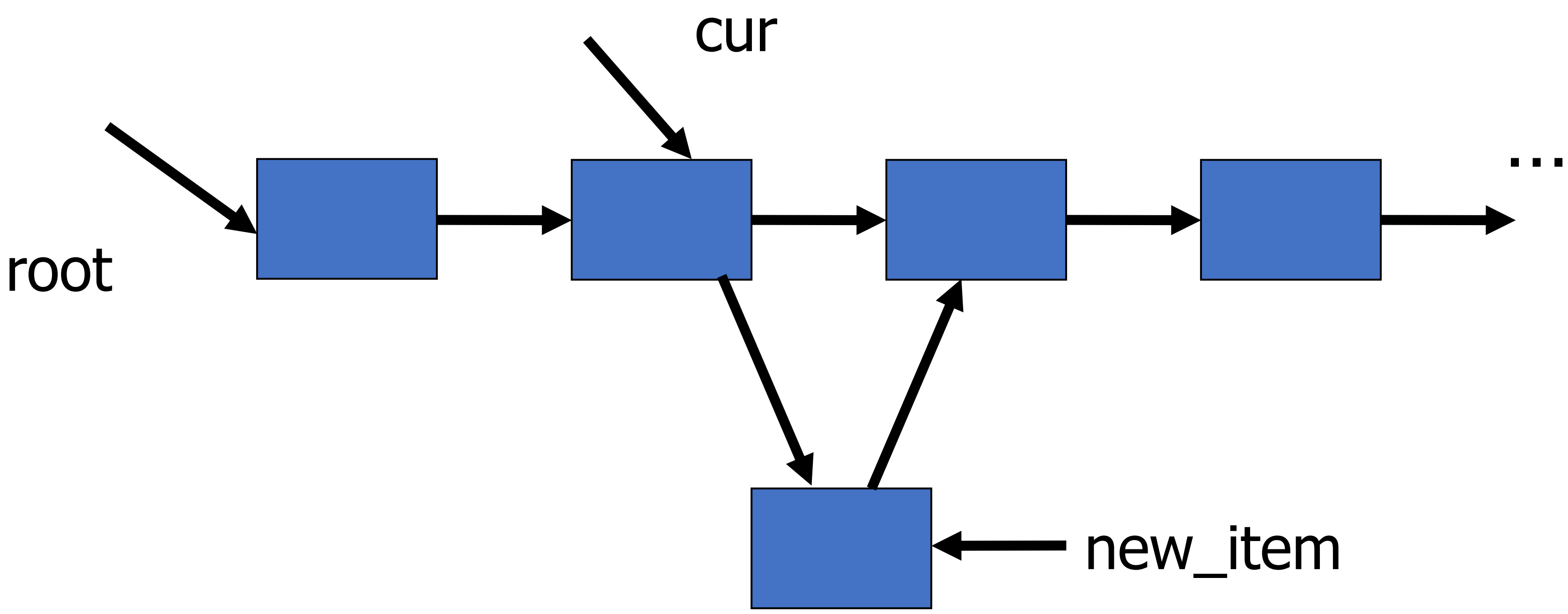


```
Name:Cao Dung
Phone number:030035888
Email:caodung@gmail.com
Cao Dung            030035888      caodung@gmail.com        0000000000000000
Name:Ha Ho
Phone number:0912221122
Email:haho@gmail.com
Ha Ho               0912221122     haho@gmail.com           0000000000026A60
```

Insert new node after the current node

- Pseudo code

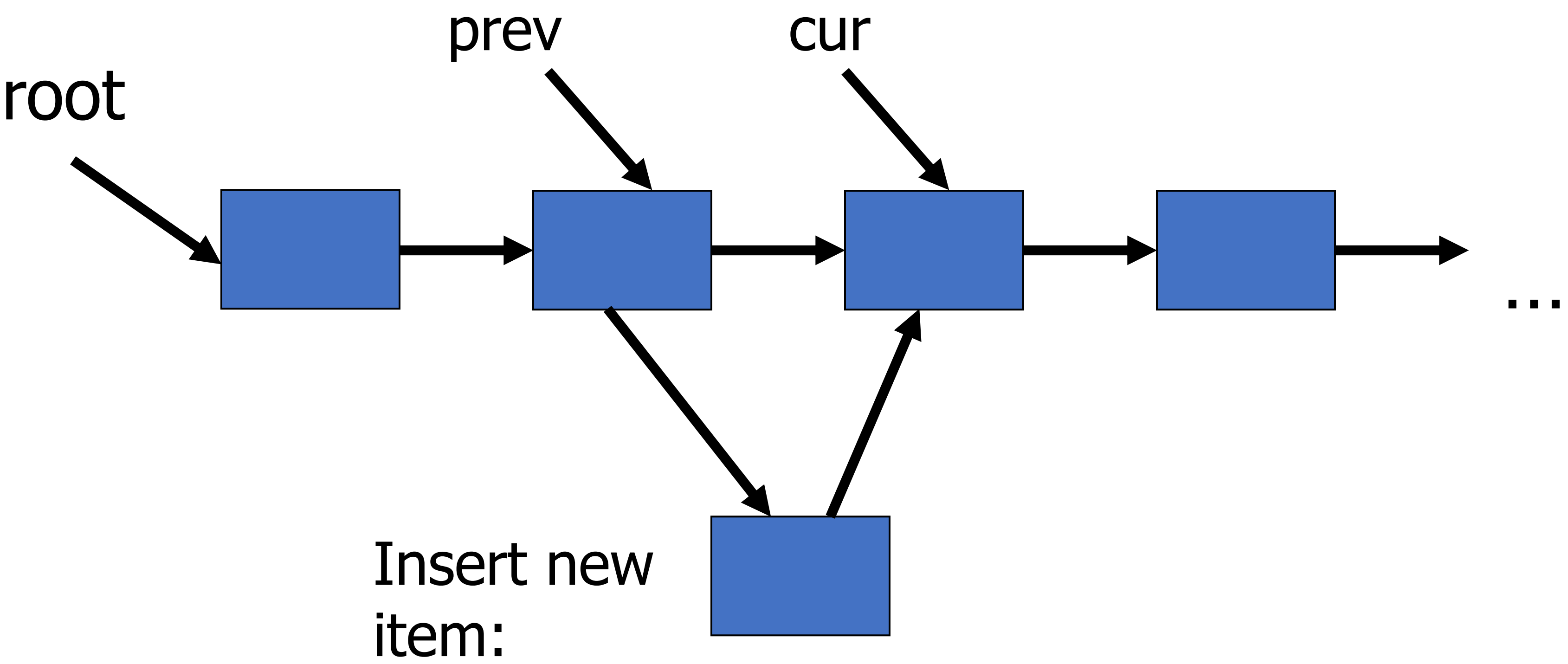
```
create new_item
new->next = cur->next;
cur->next = new;
cur= cur->next;
```



Insert new node after the current node

```
new = makeNewNode(ct); // ct is a contact data
if ( root == NULL ) {/* if there is no element */
    root = new;
    cur = root;
}
else if (cur == NULL) return;
else {
    new->next=cur->next;
    cur->next = new;
    /* prev=cur; */
    cur = cur->next;
}
```

Insert node before current position



Function: insertBeforeCurrent

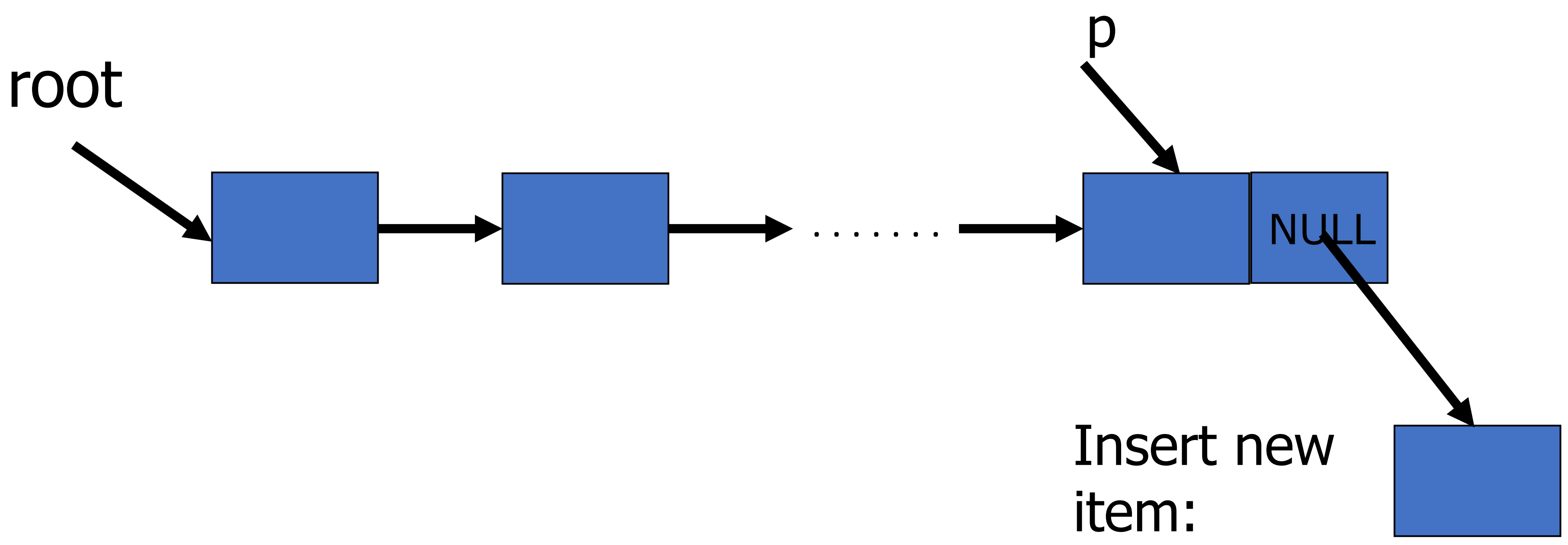
```
void insertBeforeCurrent(contact e) {
   node_addr * new = makeNewNode(e);
    if ( root == NULL ) {  /* if there is no element */
       root = new;
       cur = root;
       prev = NULL;
  } else {
       new->next=cur;
       if (cur==root) {/* if cur pointed to first element */
              root = new; /* nut moi them vao tro thanh dau danh sach */
       }
       else prev->next = new; // assume prev pointer always point to the previous node
       cur = new;
  }
}
```

If you do not frequently update the pointer prev

```
/* determine prev */
tmp = root;
 while (tmp!=NULL && tmp->next!=cur && cur !=NULL)
        tmp=tmp->next;
 prev = tmp;
```

Insert node at the end of the list

- Identify pointer p which points to the last node (next pointer is NULL)



Insert node at the end of the list : solution

```
void insertAtTail(contact ct){
  node* new = makeNewNode(ct);
 if (root == NULL) { root = new; cur = new; prev = NULL; return;
 }
 node* p = root;
 while (p->next !=NULL) p=p->next;
 p->next = new;
 cur = new; prev = p;
}
void main(){
  contact tmp; int i;
  for(i=0;i<2;i++){
     tmp = readNode(); insertAtTail(tmp);
     displayNode(root);
   }
}
```

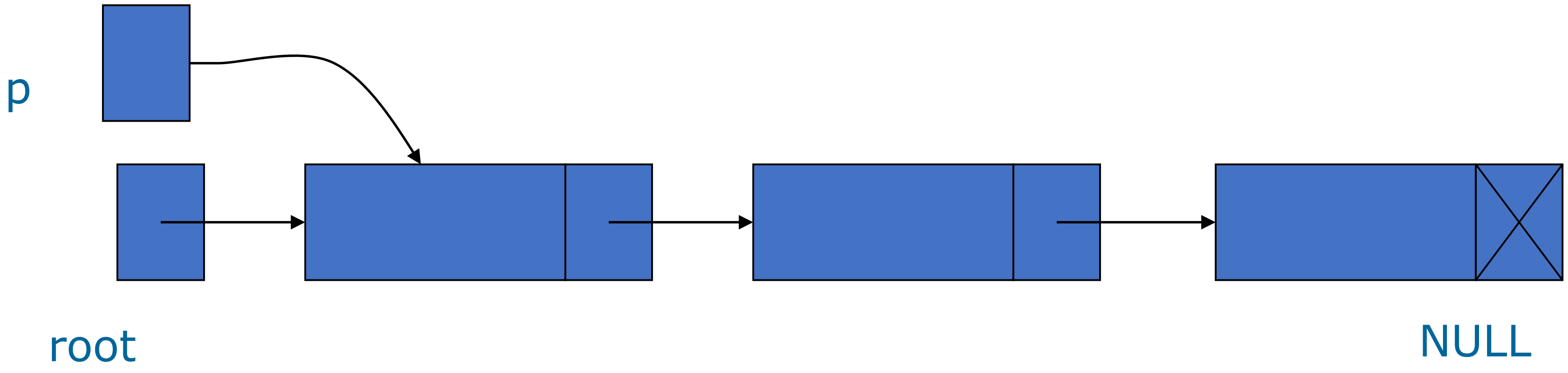
Insert node at the end of the list : version using recursion

```
node* insertLastRecursive(node* root, contact ct){
    if(root == NULL){
        return makeNewNode(ct);
    }
    root->next = insertLastRecursive(root->next, ct);
    return root;
}
void main(){
  contact tmp; int i;
  for(i=0;i<2;i++){
     tmp = readNode(); root = insertLastRecursive(tmp);
     displayNode(root);
   }
}
```

Navigate (traverse) the linked list

- Necessary in tasks such as displaying list's content or copying list
- The traversing is finished if the last node is reached

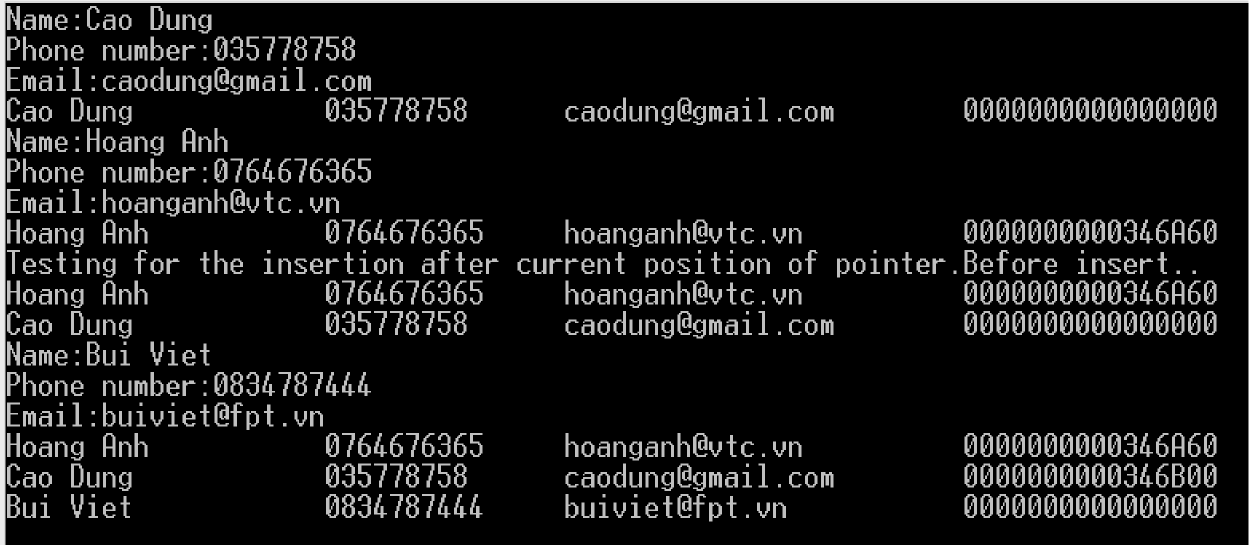
```
void traversingList(node *root){
node * p;
for ( p = root; p!= NULL; p = p->next )
  displayNode(p);
}
```



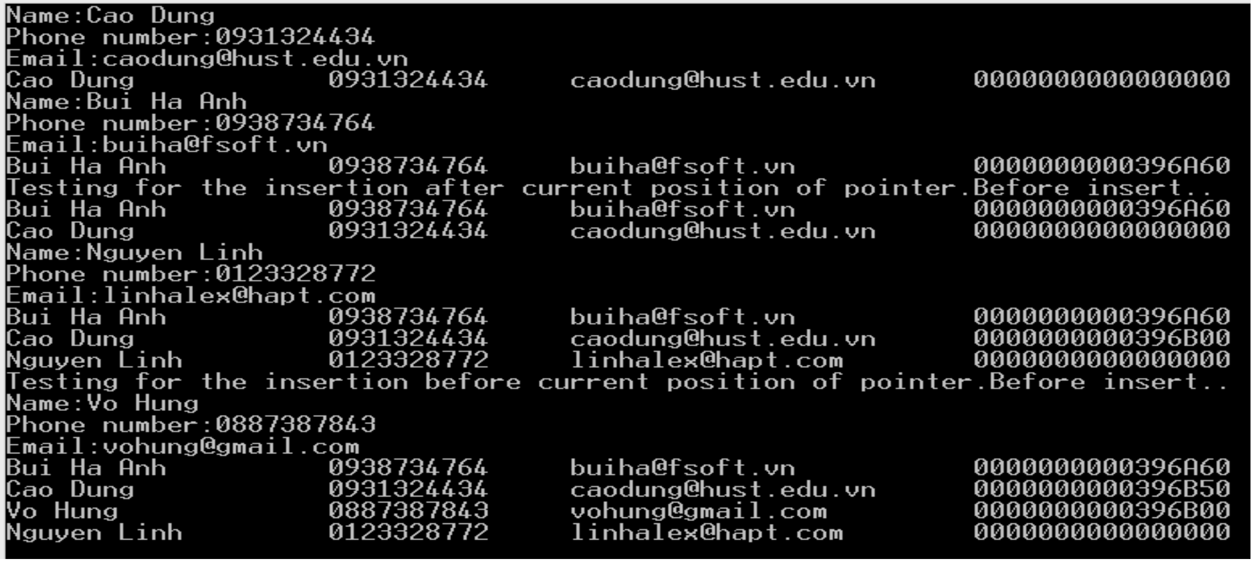
Using the functions to create and display a linked list

- Using a loop to input data to Linked List then display the whole list.

```
void main(){
   n=5;
    while (n){
      node tmp = readNode();
      insertAtHead(tmp);
     // or insertAfter..
       n--;
    }
    traversingList(root);
}
```



```
Name:Cao Dung
Phone number:035778758
Email:caodung@gmail.com
Cao Dung            035778758      caodung@gmail.com        0000000000000000
Name:Hoang Anh
Phone number:0764676365
Email:hoanganh@vtc.vn
Hoang Anh           0764676365     hoanganh@vtc.vn          0000000000346A60
Testing for the insertion after current position of pointer.Before insert..
Hoang Anh           0764676365     hoanganh@vtc.vn          0000000000346A60
Cao Dung            035778758      caodung@gmail.com        0000000000000000
Name:Bui Viet
Phone number:0834787444
Email:buiviet@fpt.vn
Hoang Anh           0764676365     hoanganh@vtc.vn          0000000000346A60
Cao Dung            035778758      caodung@gmail.com        0000000000346B00
Bui Viet            0834787444     buiviet@fpt.vn           0000000000000000
```



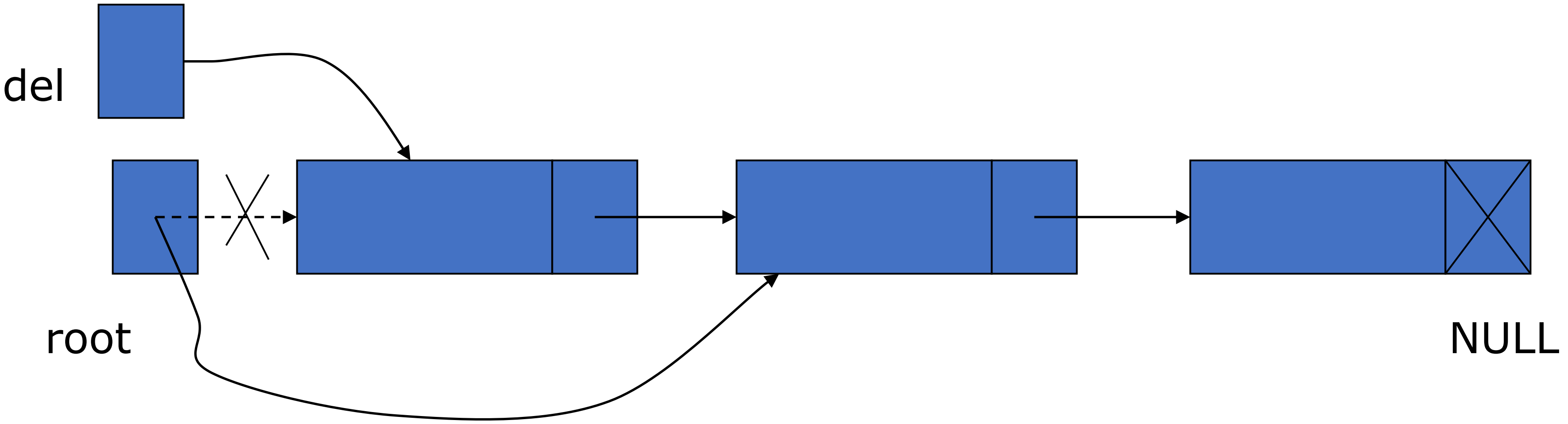
```
Name:Cao Dung
Phone number:0931324434
Email:caodung@hust.edu.vn
Cao Dung            0931324434     caodung@hust.edu.vn      0000000000000000
Name:Bui Ha Anh
Phone number:0938734764
Email:buiha@fsoft.vn
Bui Ha Anh          0938734764     buiha@fsoft.vn           0000000000396A60
Testing for the insertion after current position of pointer.Before insert..
Bui Ha Anh          0938734764     buiha@fsoft.vn           0000000000396A60
Cao Dung            0931324434     caodung@hust.edu.vn      0000000000000000
Name:Nguyen Linh
Phone number:0123328772
Email:linhalex@hapt.com
Bui Ha Anh          0938734764     buiha@fsoft.vn           0000000000396A60
Cao Dung            0931324434     caodung@hust.edu.vn      0000000000396B00
Nguyen Linh         0123328772     linhalex@hapt.com        0000000000000000
Testing for the insertion before current position of pointer.Before insert..
Name:Vo Hung
Phone number:0887387843
Email:vohung@gmail.com
Bui Ha Anh          0938734764     buiha@fsoft.vn           0000000000396A60
Cao Dung            0931324434     caodung@hust.edu.vn      0000000000396B50
Vo Hung             0887387843     vohung@gmail.com         0000000000396B00
Nguyen Linh         0123328772     linhalex@hapt.com        0000000000000000
```

Delete first element of the List

- Write a function that delete the first element of the list
- Logic:

```
del=root; root = del->next; free(del);
```

- Change the value of “root” into the value of “next” which is pointed by “del.”



Delete first element of the list

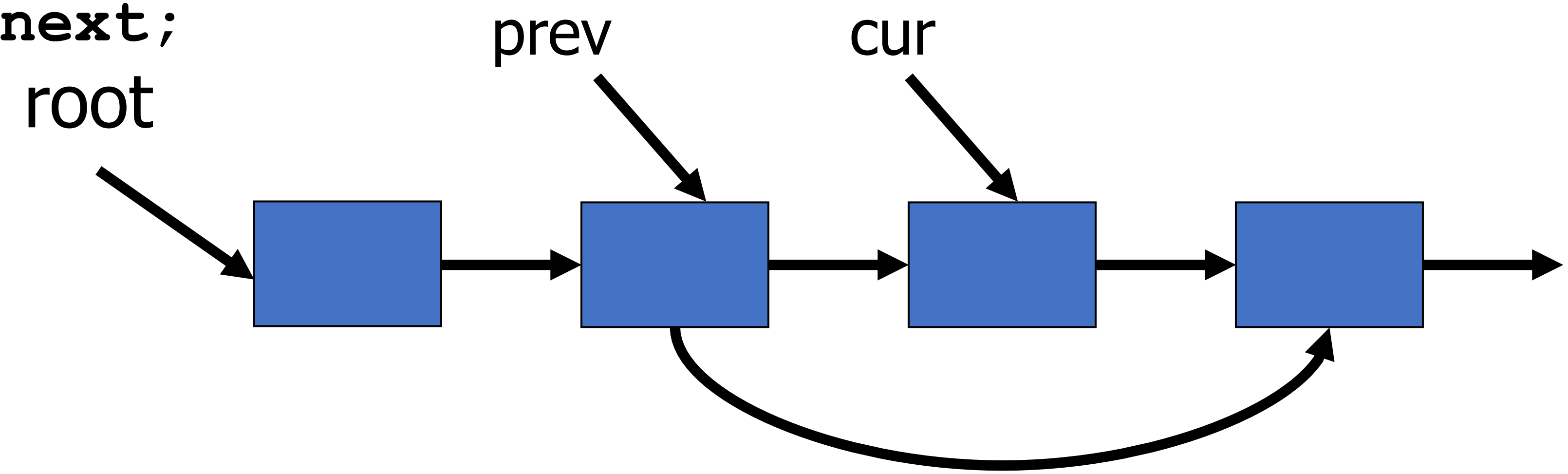
```
void deleteFirstElement(){
 node* del = root;
 if (del == NULL) return;
 root = del->next;
 free(del);
 cur = root;
 prev = NULL;
}
```

Delete an element from the middle

- Remove the node pointed by the pointer cur (current node).
  - Design and implement of ***deleteCurrentElement*** function

- Logic: Use pointer prev which point to the node just before the node to delete

```
prev->next = cur->next;
free(cur);
cur = prev->next;
```



Solution: Delete element pointed by cur

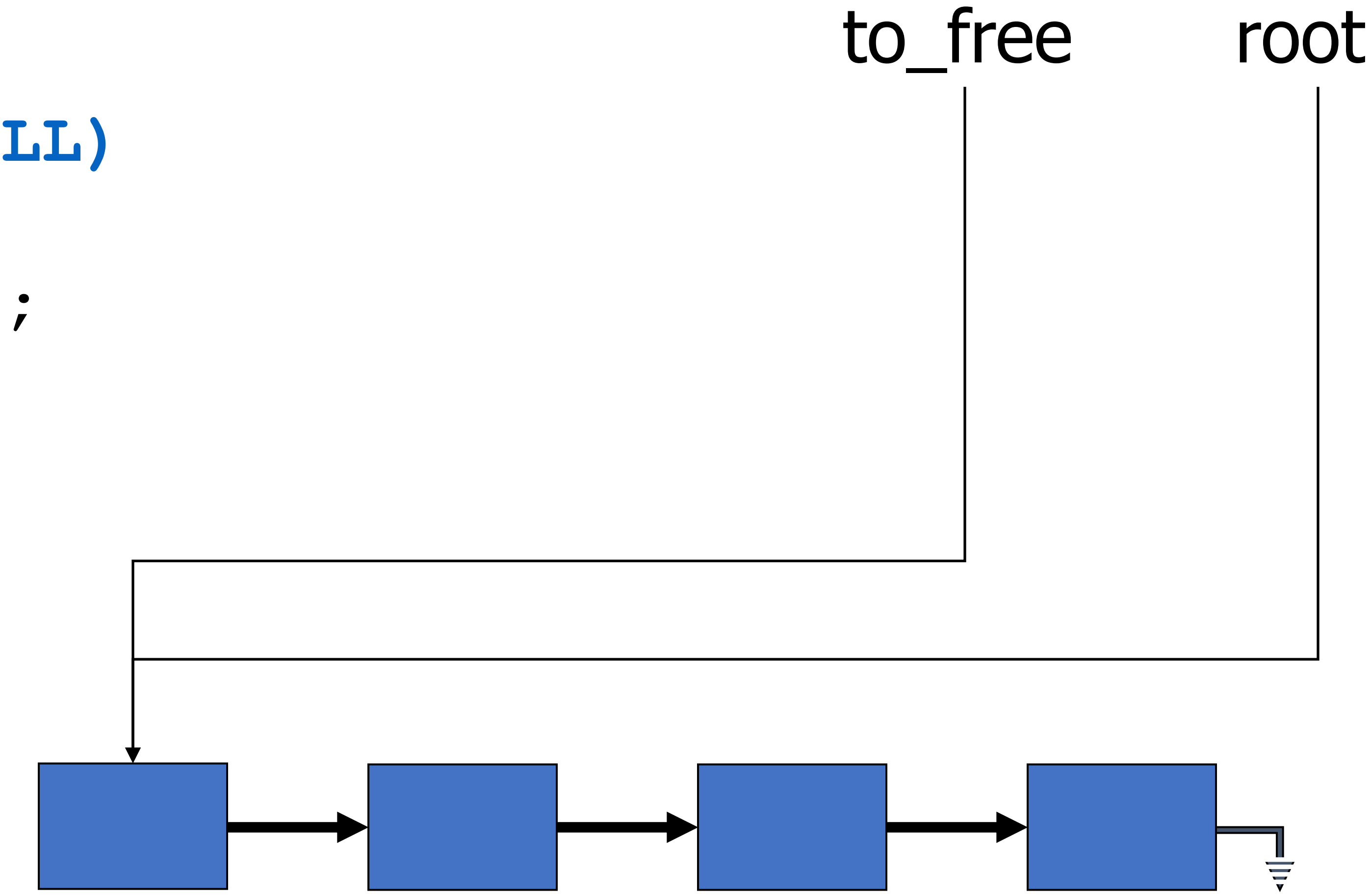
```
void deleteCurrentElement(){
 if (cur==NULL) return;
 if (cur==root) deleteFirstElement();
 else {
  prev->next = cur->next;
 free(cur);
 cur = prev->next; // or cur = root;
}
```

Delete a node with a specific contact (using recursion)

```
Node* removeNodeRecursive(Node* root, contact e){
    if(root == NULL) return NULL;
    if(root->el == e){
        Node* tmp = root; root = root->next; free(tmp);
        return root;
    }
    root->next = removeNodeRecursive(root->next, e);
    return root;
}
```

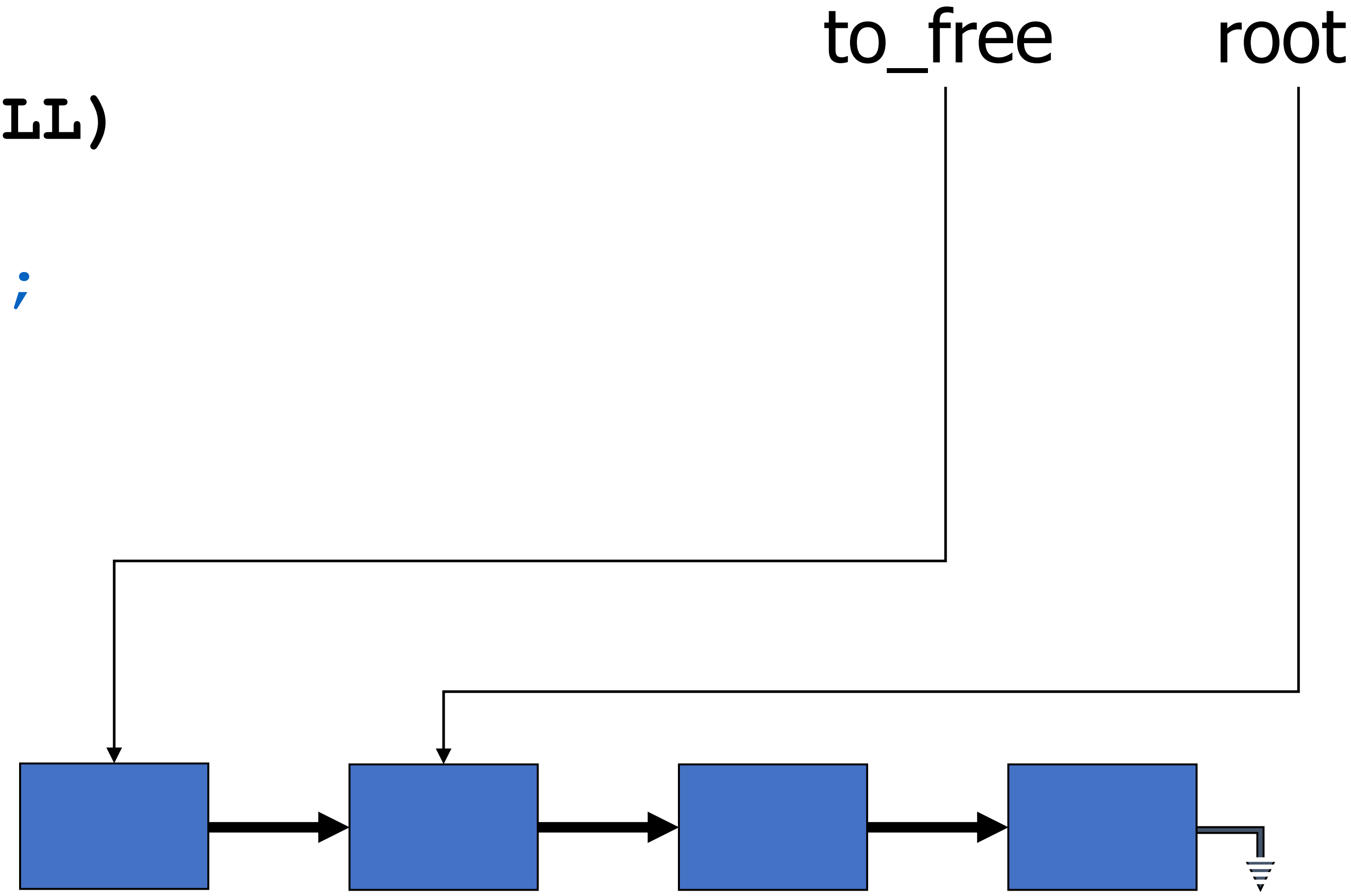
Freeing all nodes of a list

```
to_free = root ;
while (to_free != NULL)
{
    root = root->next;
    free(to_free);
    to_free = root;
}
```



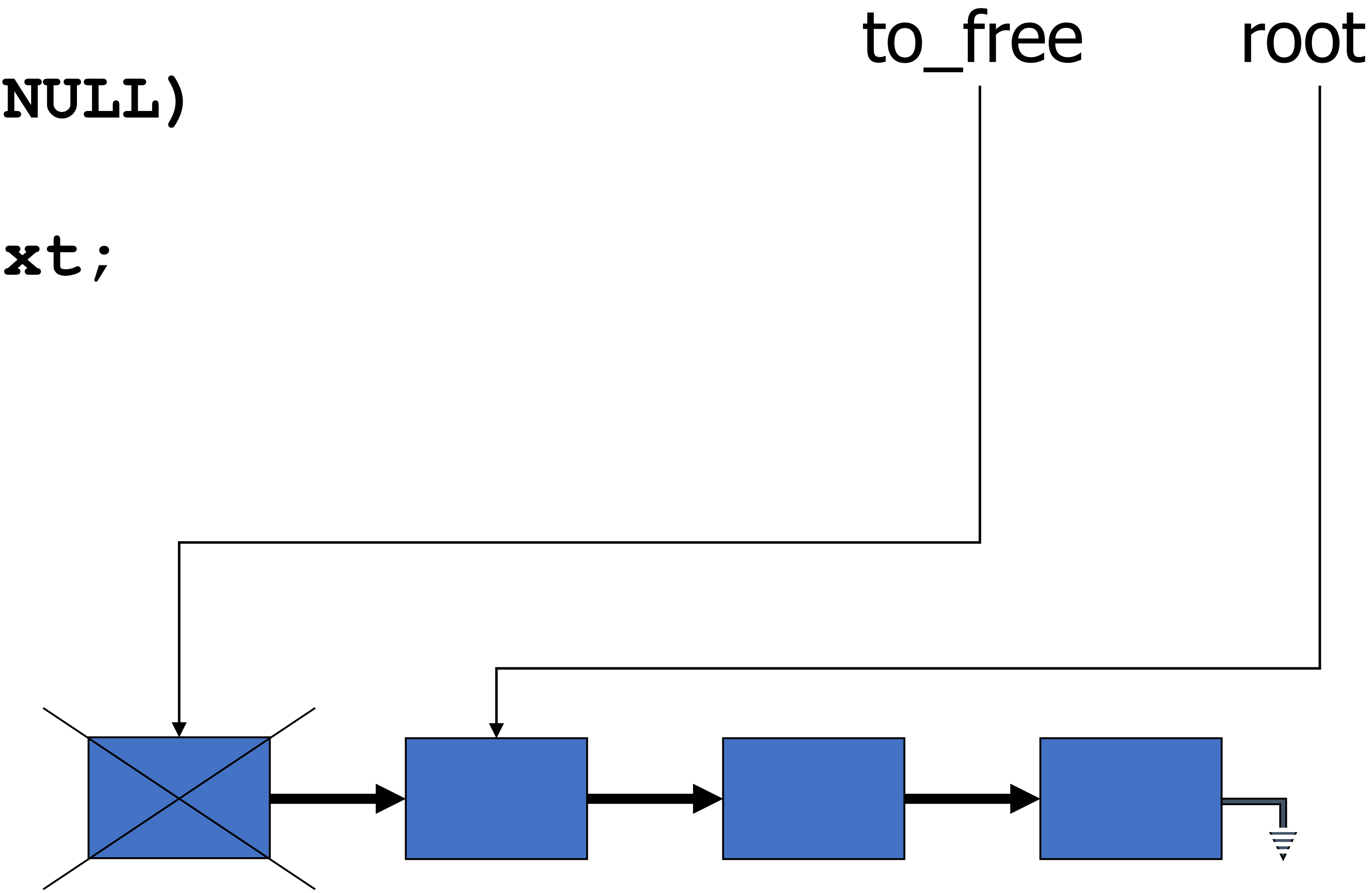
Freeing all nodes of a list

```
to_free = root ;
while (to_free != NULL)
{
    root = root->next;
    free(to_free);
    to_free = root;
}
```



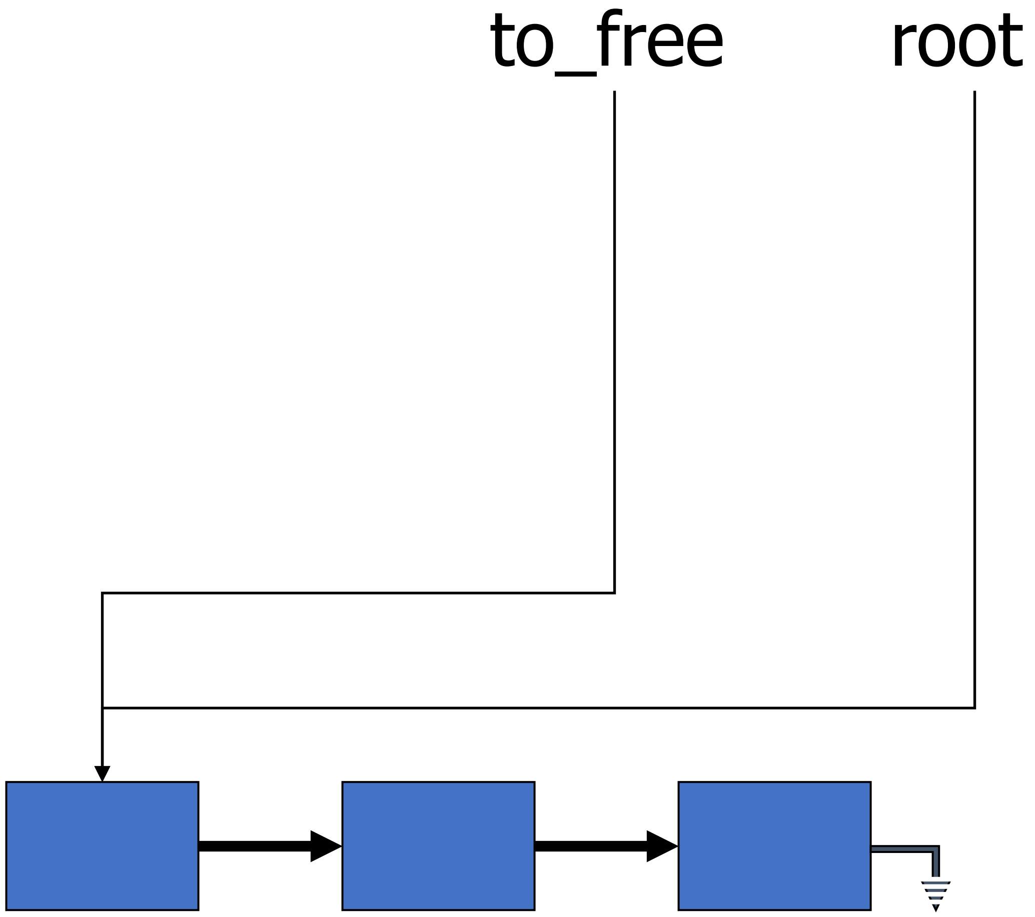
Freeing all nodes of a list

```
while (to_free != NULL)
{
    root = root->next;
    free(to_free);
    to_free = root;
}
```



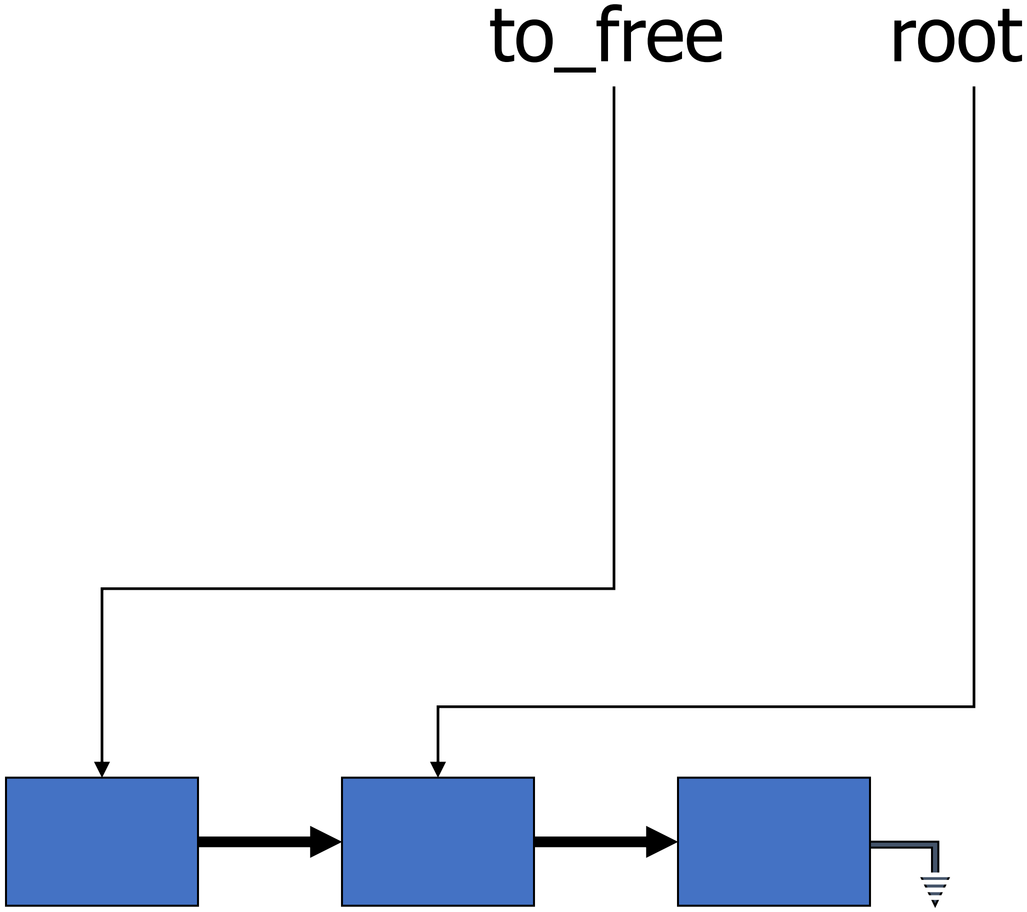
Freeing all nodes of a list

```
while (to_free != NULL)
{
    root = root->next;
    free(to_free);
    to_free = root;
}
```



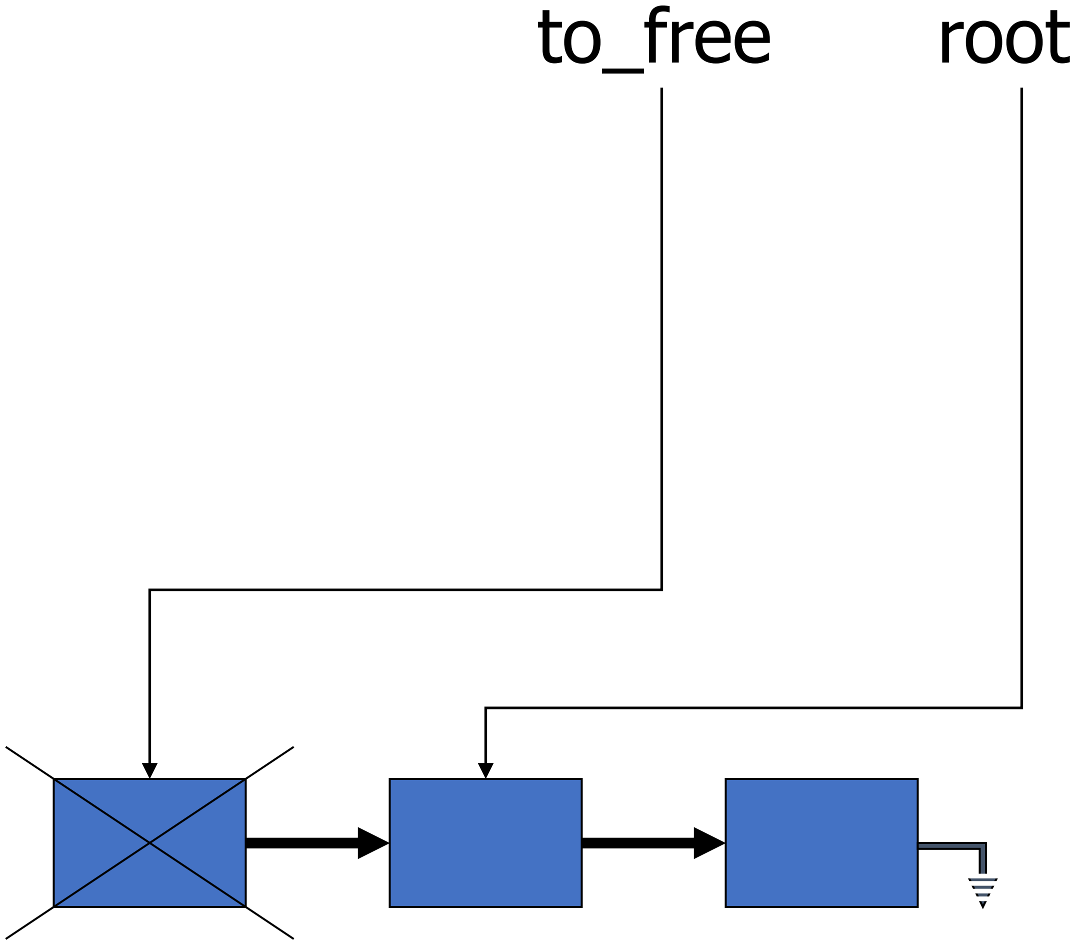
Freeing all nodes of a list

```
while (to_free != NULL)
{
    root = root->next;
    free(to_free);
    to_free = root;
}
```



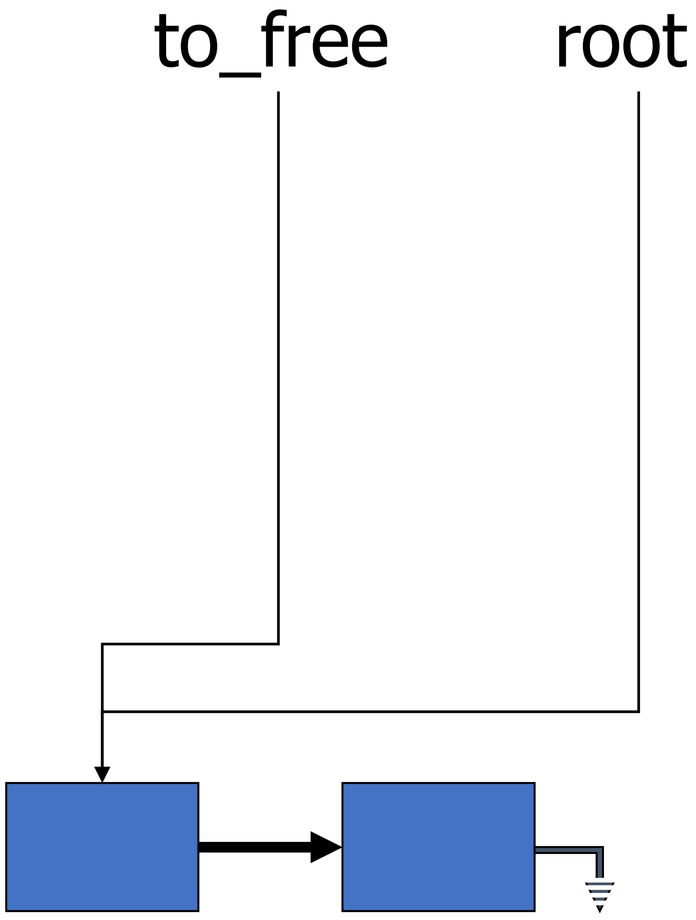
Freeing all nodes of a list

```
while (to_free != NULL)
{
    root = root->next;
    free(to_free);
    to_free = root;
}
```



Freeing all nodes of a list

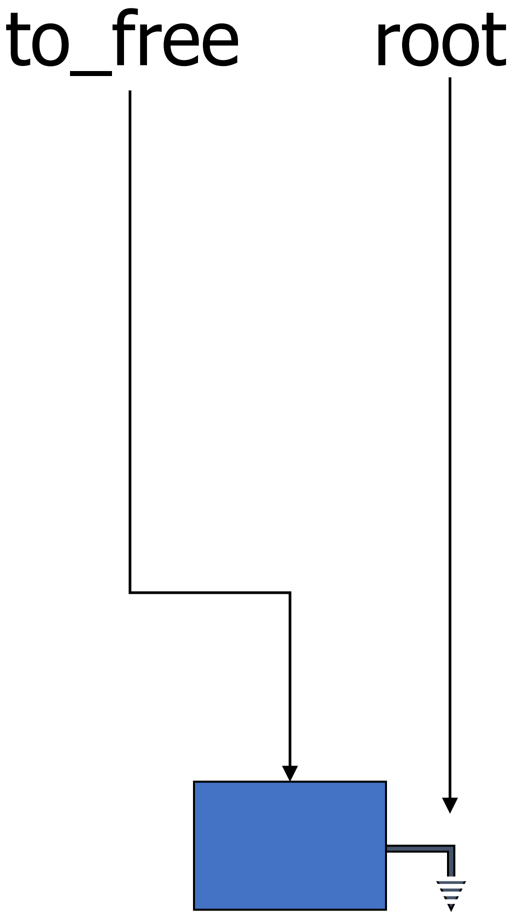
```
while (to_free != NULL)
{
    root = root->next;
    free(to_free);
    to_free = root;
}
```



Freeing all nodes of a list

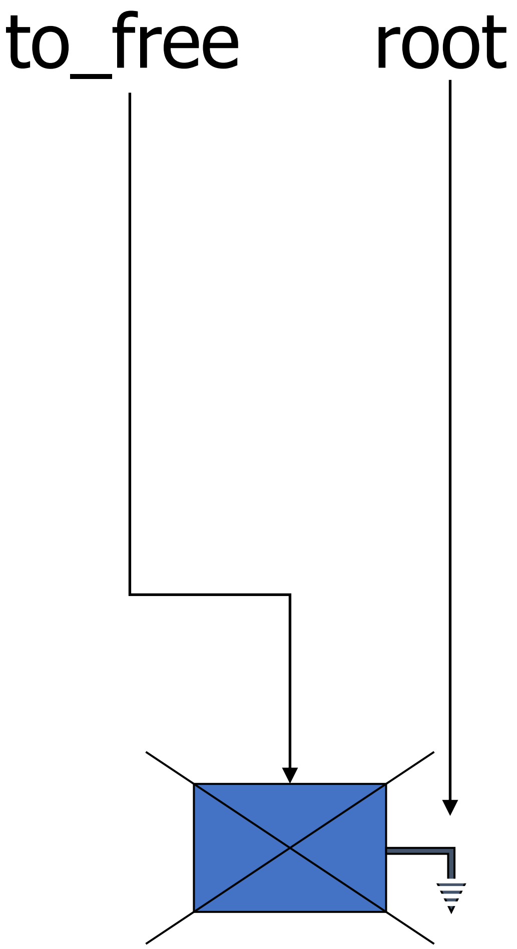
- After some iteration …

```
while (to_free != NULL)
{
    root = root->next;
    free(to_free);
    to_free = root;
}
```



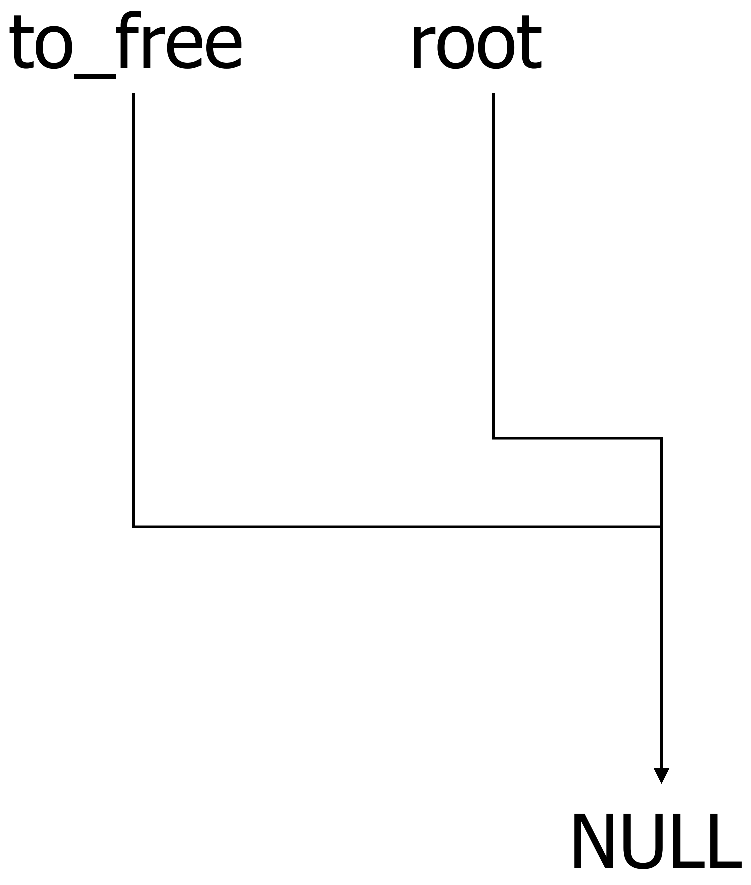
Freeing all nodes of a list

```
while (to_free != NULL)
{
    root = root->next;
    free(to_free);
    to_free = root;
}
```



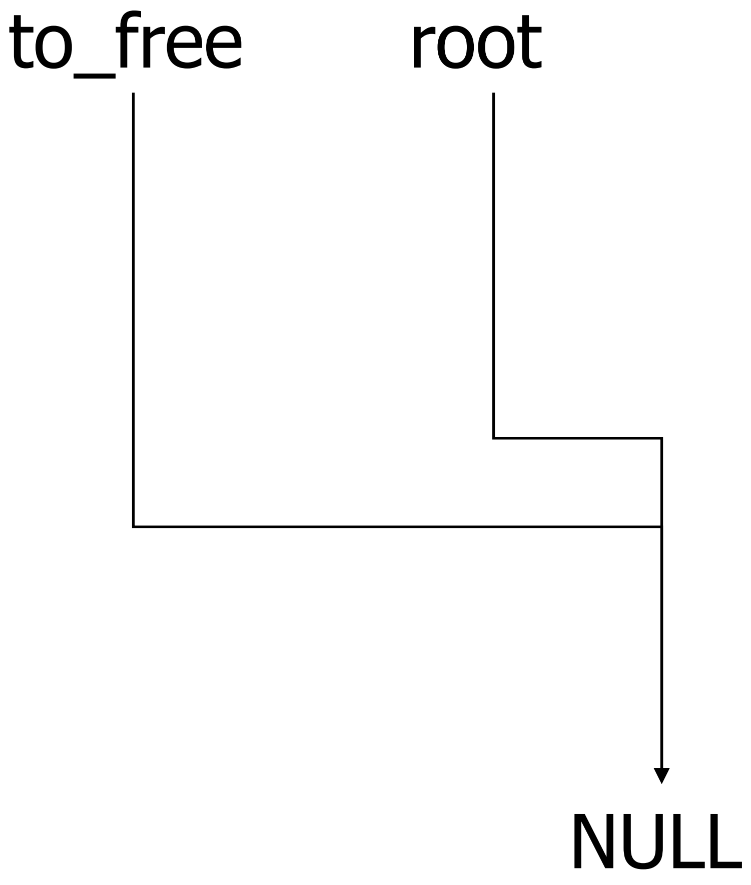
Freeing all nodes of a list

```
while (to_free != NULL)
{
    root = root->next;
    free(to_free);
    to_free = root;
}
```



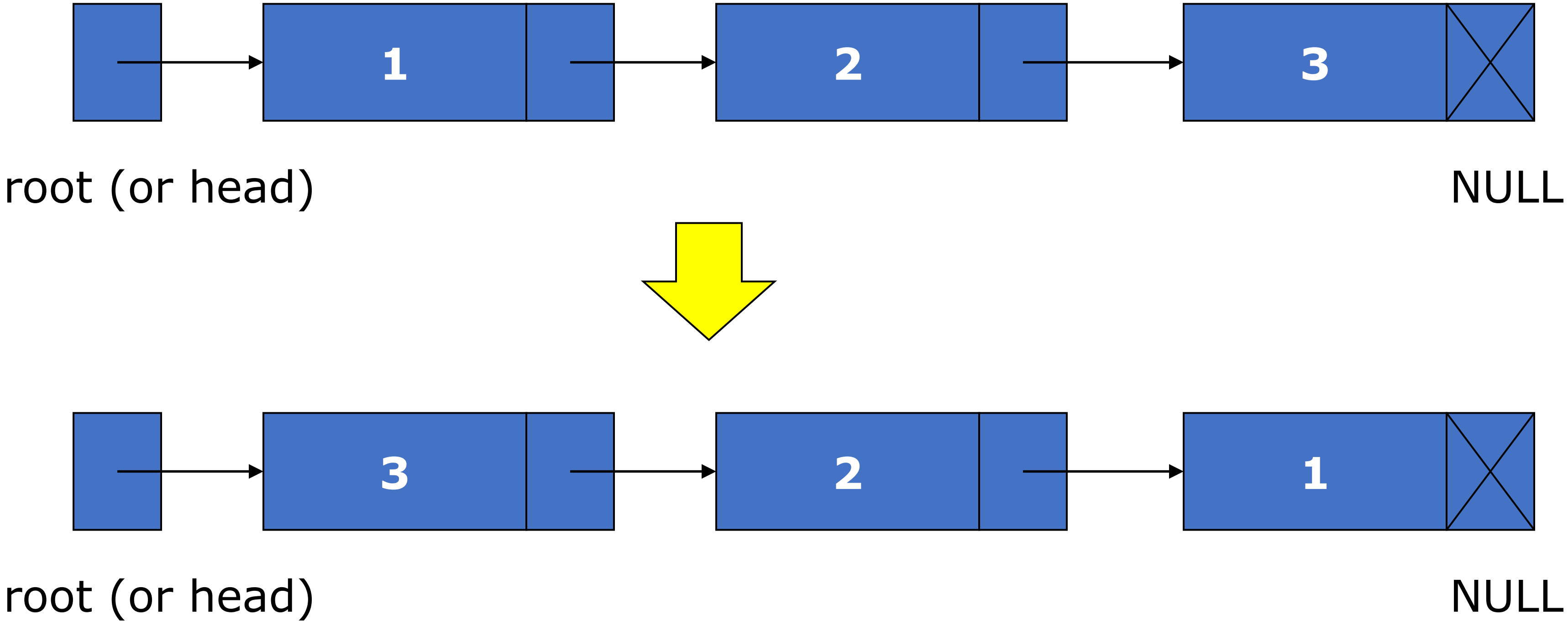
Freeing all nodes of a list

```
while (to_free != NULL)
{
    root = root->next;
    free(to_free);
    to_free = root;
}
```



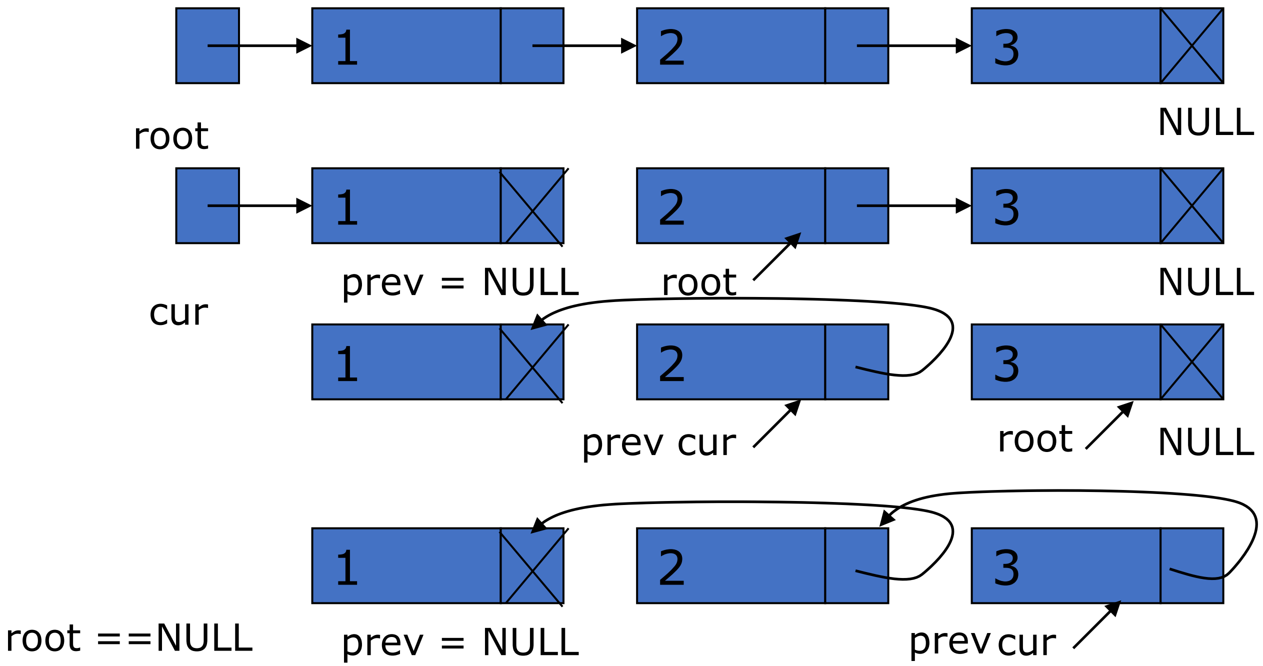
Reverse a list

- Write a function that reverse the content a list.

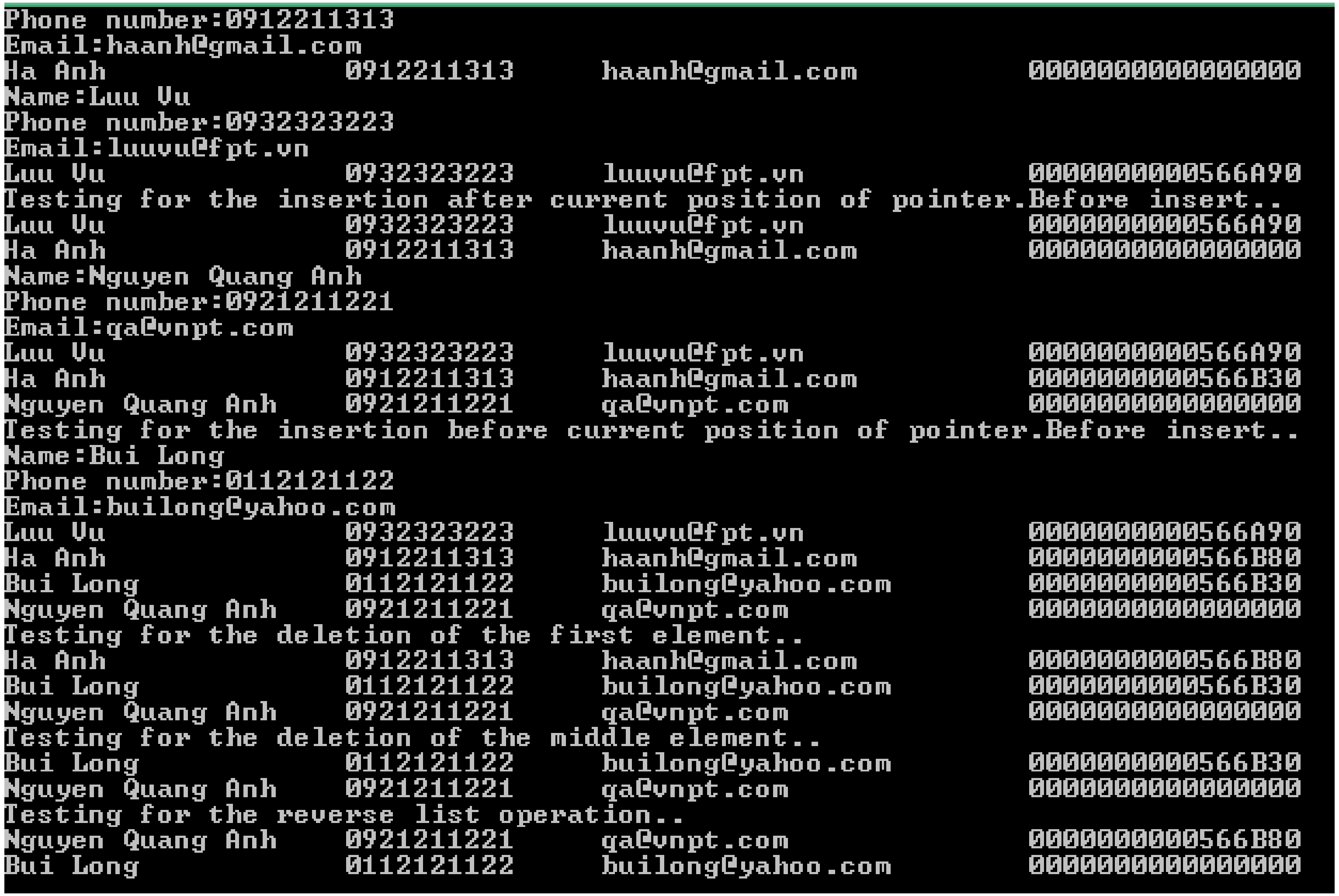


Solution

```
node* list_reverse (node* root)
{
  node *cur, *prev;
  cur = prev = NULL;
  while (root != NULL) {
      cur = root;
      root = root->next;
      cur->next = prev;
      prev = cur;
  }
  return prev;
}
```



Program Output



```
Phone number:0912211313
Email:haanh@gmail.com
Ha Anh              0912211313     haanh@gmail.com          0000000000000000
Name:Luu Vu
Phone number:0932323223
Email:luuvu@fpt.vn
Luu Vu              0932323223     luuvu@fpt.vn             0000000000566A90
Testing for the insertion after current position of pointer.Before insert..
Luu Vu              0932323223     luuvu@fpt.vn             0000000000566A90
Ha Anh              0912211313     haanh@gmail.com          0000000000000000
Name:Nguyen Quang Anh
Phone number:0921211221
Email:qa@vnpt.com
Luu Vu              0932323223     luuvu@fpt.vn             0000000000566A90
Ha Anh              0912211313     haanh@gmail.com          0000000000566B30
Nguyen Quang Anh    0921211221     qa@vnpt.com              0000000000000000
Testing for the insertion before current position of pointer.Before insert..
Name:Bui Long
Phone number:0112121122
Email:builong@yahoo.com
Luu Vu              0932323223     luuvu@fpt.vn             0000000000566A90
Ha Anh              0912211313     haanh@gmail.com          0000000000566B80
Bui Long            0112121122     builong@yahoo.com        0000000000566B30
Nguyen Quang Anh    0921211221     qa@vnpt.com              0000000000000000
Testing for the deletion of the first element..
Ha Anh              0912211313     haanh@gmail.com          0000000000566B80
Bui Long            0112121122     builong@yahoo.com        0000000000566B30
Nguyen Quang Anh    0921211221     qa@vnpt.com              0000000000000000
Testing for the deletion of the middle element..
Bui Long            0112121122     builong@yahoo.com        0000000000566B30
Nguyen Quang Anh    0921211221     qa@vnpt.com              0000000000000000
Testing for the reverse list operation..
Nguyen Quang Anh    0921211221     qa@vnpt.com              0000000000566B80
Bui Long            0112121122     builong@yahoo.com        0000000000000000
```

Outline

- Introduction to linked list
- Implementation of singly linked list data structure
- **Using list in specific problems**

Lab 1: Linked list manipulation

- Write a program to perform the following tasks:
  - Build a linked list with the initially provided keys as the sequence a_1, a_2, …, a_n.
  - Perform the following operations on the list:
    - adding 1 element to the beginning, to the end of the list,
    - go before or after an element in the list,
    - or remove an element from the list
- Submit the program on the automatic evaluation system

Input and output format

- **Input**
- Line 1: input a positive integer n (1 <= n <= 1000)
- Line 2: series of n positive integer numbers a_1, a_2, ..., a_n.
- The next lines are commands (ending with the # symbol) :
- **addlast k**: add element with key k to the end of the list (if k does not already exist)
- **addfirst k**: add element with key k to the beginning of the list (if k does not already exist)
- **addafter u v:** add element with key equal to u after element with key equal to v on the list (if v already exists on the list and u does not exist yet)
- **addbefore u v**: add the element with key equal to u before the element with key equal to v on the list (if v already exists on the list and u does not exist)
- **remove k**: remove the element with key k from the list
- **reverse**: reverses the order of list elements (no new elements can be allocated, only links can be changed)
- **Output:** Displays the key sequence of the list obtained after a given sequence of operation commands

Example for input and output

Input

```
5
5 4 3 2 1
addlast 3
addlast 10
addfirst 1
addafter 10 4
remove 1
#
```

Output

```
5 4 3 2 10
```

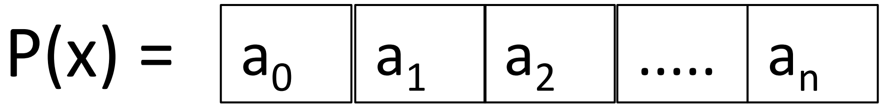
Polynomial manipulation

- A polynomial p(x) is the expression in variable x which is in the form $a_nx^n + a_{n-1}x^{n-1} + ... + a_1x + a_{0,}$
  - where a_i fall in the category of real numbers
  - n is non negative integer, which is called the degree of polynomial.

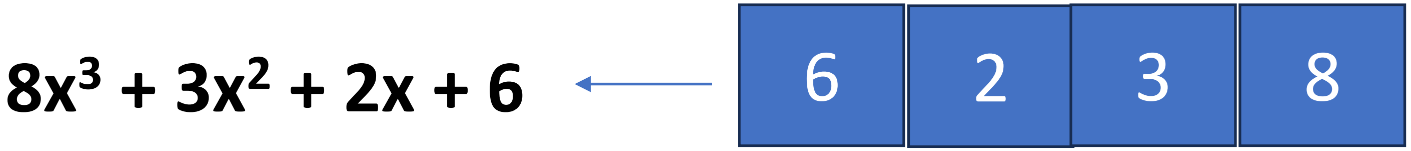
- Some basic operations in Polynomial manipulation
  - Polynomial creation (representation)
  - Addition (subtraction) of polynomials
  - Multiplication of polynomials

Polynomial representation using arrays

- Coefficients are stored in the elements in an array at corresponding subscript (index)
- Indexes represent exponents

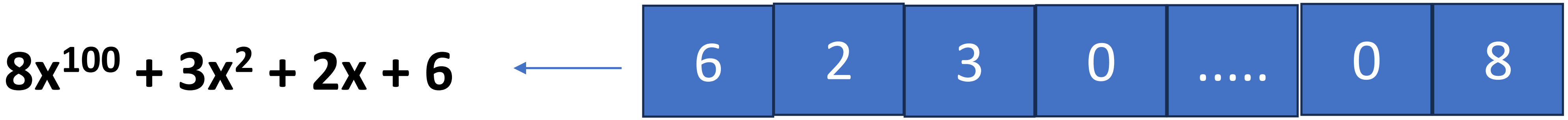


P(x) = | a_0 | a_1 | a_2 | ..... | a_n |



$8x^3 + 3x^2 + 2x + 6$ ← | 6 | 2 | 3 | 8 |

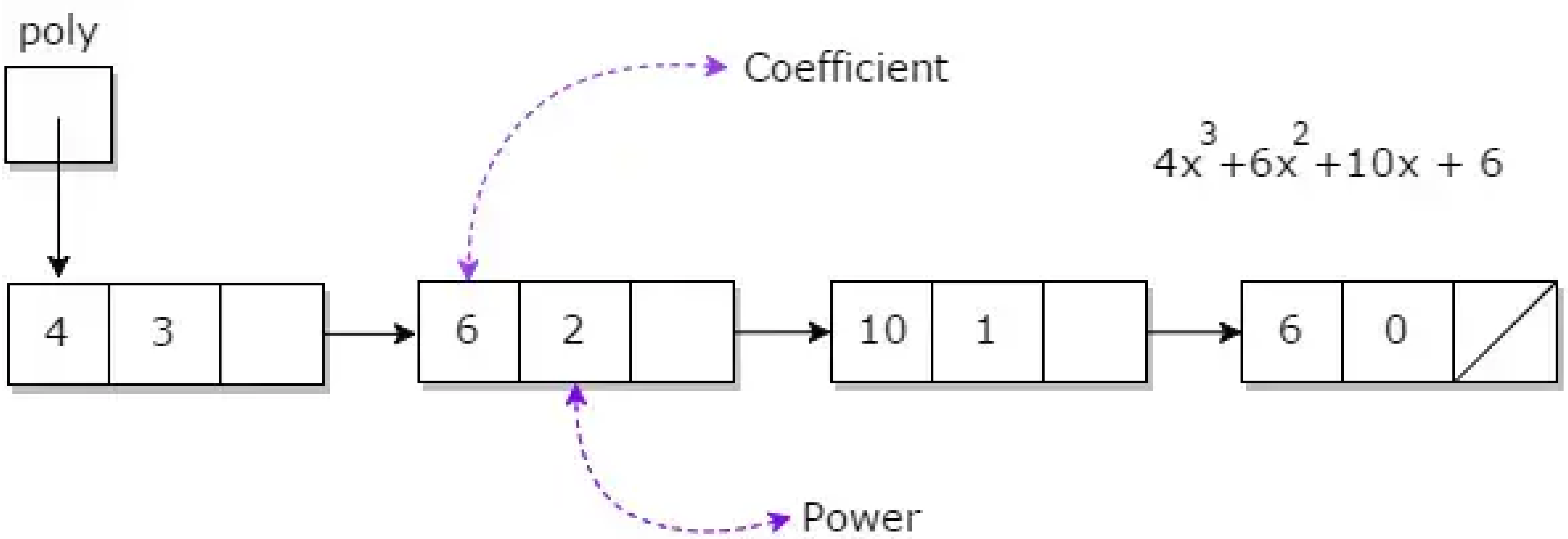
- Limitation: waste lot of memory spaces for sparse polynomials.



$8x^{100} + 3x^2 + 2x + 6$ ← | 6 | 2 | 3 | 0 | ..... | 0 | 8 |

Polynomial representation using linked list

- Each term is stored in a node of the list with 2 fields: coefficient and exponent
- Nodes are always sorted in a decreasing order of exponents
- No two nodes have the same value of exponents
- Save spaces for every polynomials



Lab2: Polynomial manipulation

- Write a program providing a list of commands over polynomials below, knowing that Each polynomial has an identifier which is a positive integer from 1 to 10000:
- **Create <poly_id>:** create a polynomial with identifier <pol_id> if this polynomial does not exists, otherwise, do nothing
- **AddTerm <poly_id> <coef> <exp>:** Add a term with coefficient <coef> and exponent <exp> to the polynomial having identifier **<poly_id>** (create a new polynomial if it does not exist)
- **EvaluatePoly <poly_id> <variable_value>**: Evaluate and print the value of the polynomial having identifier <poly_id> and <variable_value> is the value of the variable (print 0 if the polynomial does not exist)
- **AddPoly <poly_id1> <poly_id2> <result_poly_id>**: Perform the addition operation over two polynomials <pol_id1> and <poly_id2>. The resulting polynomial will have identifier <result_poly_id> (if the polynomial <result_poly_id> exists, then overrides the existing polynomial)
- **PrintPoly <poly_id>:** print the polynomial <poly_id> (if it exists) to stdout under the form <c_1> <e_1> <c_2> <e_2> ... (sequence of pairs of (coefficient, exponent) of terms of the polynomial in a decreasing order of exponents)
- **Destroy <poly_id>:** destroy the polynomial having identifier <poly_id>

Input and output format

- **Input:** Each line contains a command described above (terminated by a line containing *)
- Example:

```
AddTerm 1 3 2
AddTerm 1 4 0
AddTerm 1 6 2
AddTerm 2 3 2
AddTerm 2 7 5
PrintPoly 1
PrintPoly 2
AddPoly 2 1 3
PrintPoly 3
EvaluatePoly 2 1
```

Input and output format

- **Output:** Each line contains the information printed out by the PrintPoly and EvaluatePoly above
- Example:

```
9 2 4 0
7 5 3 2
7 5 12 2 4 0
10
```

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THANK YOU !