CX1107
Data Structures and Algorithms

Linked Lists and Its Implementation

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Overview of Today Lecture

1. **What is the linked list?**
2. **How to create a linked list?**
3. **How to use the linked list?**
4. **Why do you need a linked list?**

What is the linked list?

Memory Allocation

3 scenario

1. **Known the data size before compile**
2. **Known the data size at the beginning**
3. **Unknown the data size. The size can be increased or decreased over the time while the program is running**

1. **Static Data Allocation (in stack memory)**
2. **Dynamic Data Allocation (in heap memory)**
3. **Dynamic Data with linked list structure**

Linked List

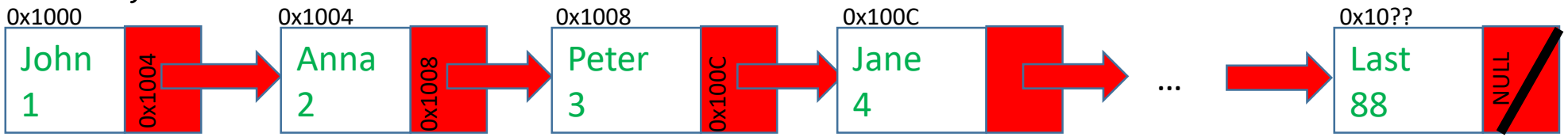
Memory Address	Name	Matric No
0x1000	John	0001
0x1004	Anna	0002
0x1008	Peter	0003
0x100C	Jane	0004
	…	…

- **Structure**: a collection of variables with different types:

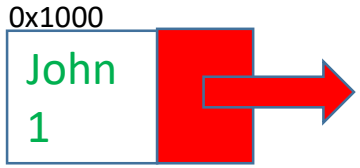
```
struct student{
        char Name[15];
        int matricNo;
}
```

- **Self-referential structure:** a pointer member that points to a structure of the same structure type

```
struct node{
        char Name[15];
        int matricNo;
        struct node *nextPtr;   //link
}
```

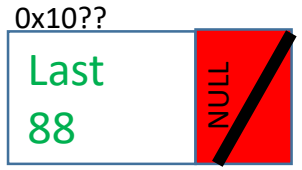


Linked List




```
struct node{
          char Name[15];
          int matricNo;
          struct node *nextPtr;  //link
}
```

1. **Each node contains data and link**
2. **The link contains the address of next node**
3. **If user knows the address of first node, the next node can be found from the link.**
4. **The link of the last node is a NULL pointer**



5. **The example is known as singly-linked list**
   - **There is only ONE link in the node**

How to create a linked list?

Definition and Declaration

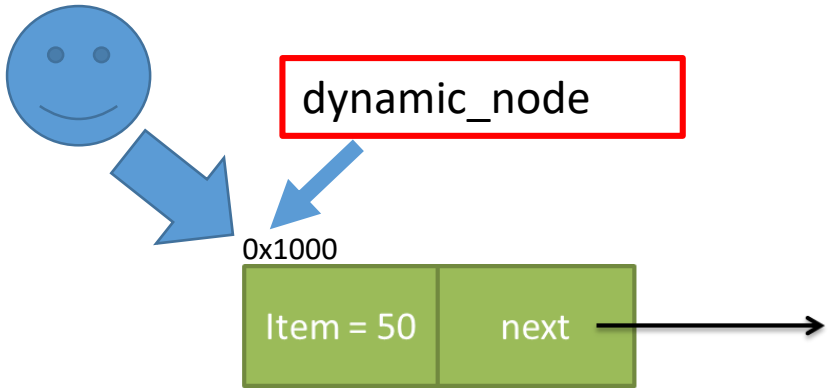
```
1  #include <stdio.h>
2  #include <stdlib.h>
3
4  struct _listnode
5  {
6      int item;
7      struct _listnode *next;
8  };
9  typedef struct _listnode ListNode;
10
11 int main(void)
12 {
13 //static node
14     ListNode static_node;
15     static_node.data = 50;
16     static_node.next = NULL;
17
18 //dynamic node
19     ListNode* dynamic_node= (ListNode*) malloc(sizeof(ListNode));
20     dynamic_node->data = 50;
21     dynamic_node->next = NULL;
22     free(dynamic_node);
23
24     return 0;
25 }
```

- Define a self-referential structure, ListNode
- Dynamically allocate a ListNode node
- Free the node
- malloc() does not allocate NULL to the next link
- free() does memory deallocation but not delete
- After dynamic_node is freed, dynamic_node is **NOT** NULL

DEFINE AND CREATE A LINKED LIST

```
 1  #include <stdio.h>
 2  #include <stdlib.h>
 3
 4  struct _listnode
 5  {
 6       int item;
 7       struct _listnode *next;
 8  };
 9  typedef struct _listnode ListNode;
10
11  int main(void)
12  {
13  //static node
14       ListNode static_node;
15       static_node.data = 50;
16       static_node.next = NULL;
17
18  //dynamic node
19       ListNode* dynamic_node=malloc(sizeof(ListNode));
20       dynamic_node->data = 50;
21       dynamic_node->next = NULL;
22
23       ListNode* head = dynamic_node;
24       free(dynamic_node);
25
26       return 0;
27  }
```

- Create a head
  - ListNode* head;
- Multiple ListNode pointers can be created but the node just need to free once in the end



What is head after line 24?

Is There any bug?

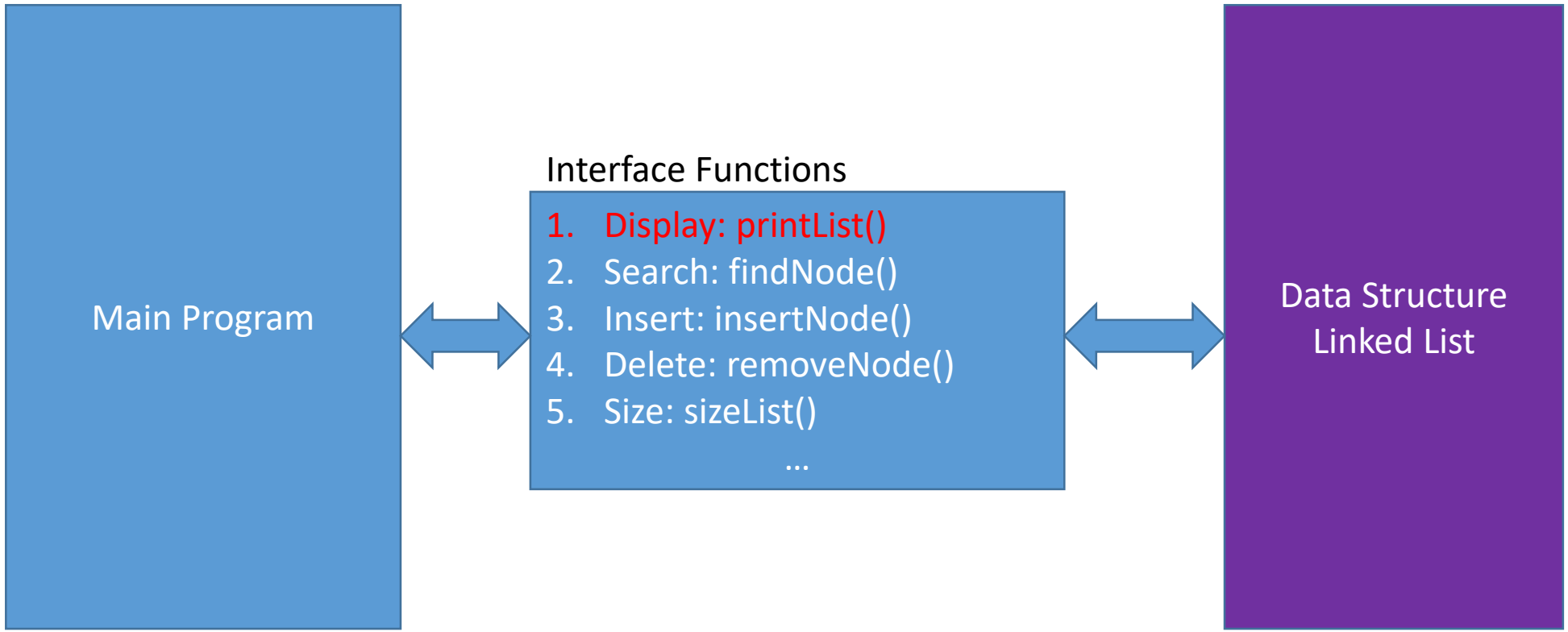
```
1  typedef struct node{
2       int item; struct node *next;
3  } ListNode;
4
5  int main(){
6       ListNode *head = NULL, *temp;
7       int i = 0;
8
9       while (scanf("%d", &i)){
10           if (head == NULL){
11                head = malloc(sizeof(ListNode));
12                temp = head;
13           }
14           else{
15                temp->next = malloc(sizeof(ListNode));
16                temp = temp->next;
17           }
18           temp->item = i;
19      }
20      temp->next = NULL;
21      return 0;
22 }
```

A. Yes

B. No

How to use the linked list?

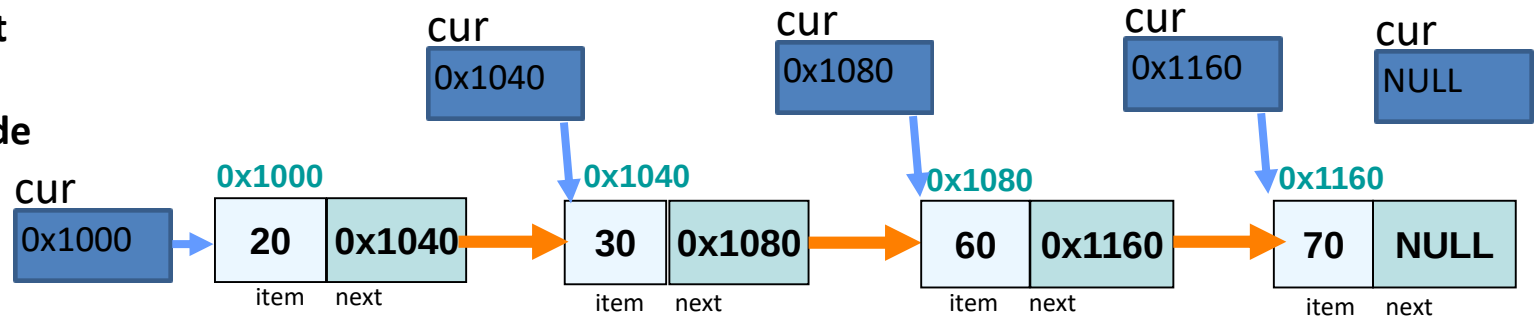
HOW TO USE THE LINKED LISTS?



DISPLAY: printList()

```
void printList(ListNode *cur);
```

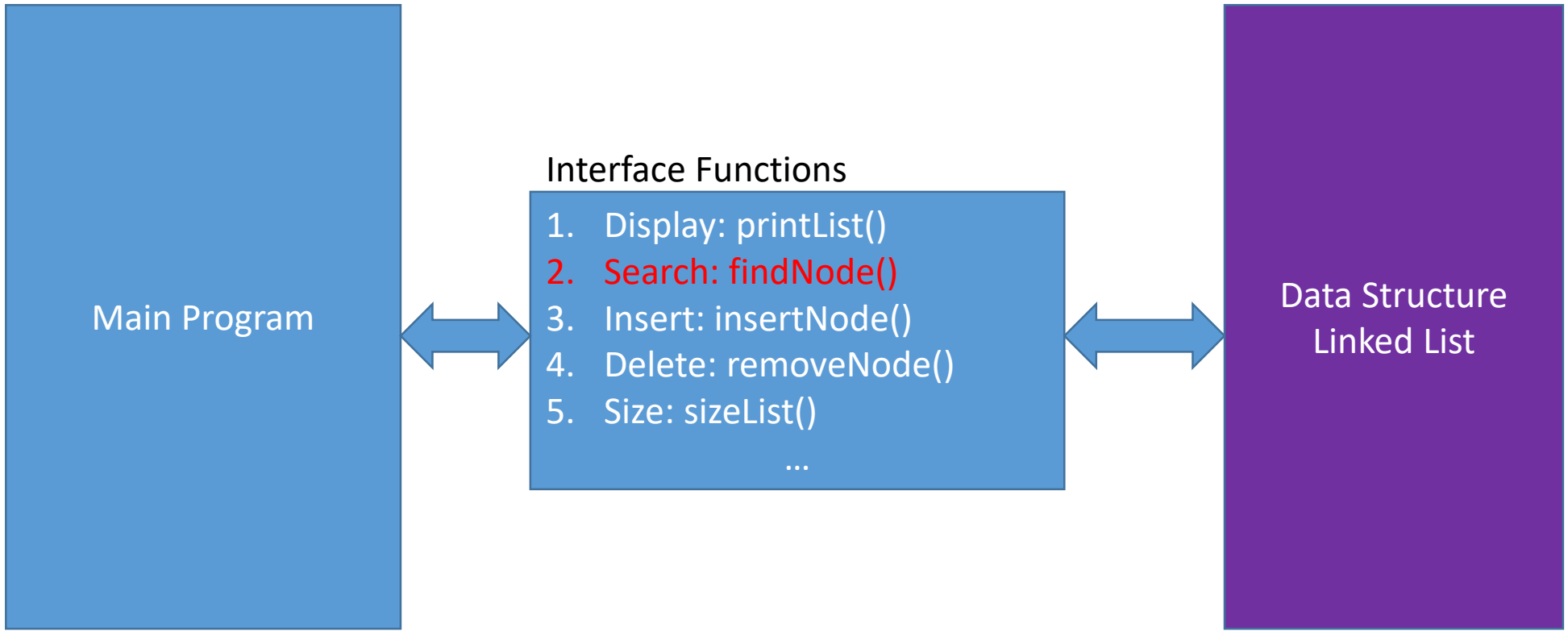
1. **Given the head pointer of the linked list**
2. **Print all items in the linked list**
3. **From first node to the last node**




```
1  void printList(ListNode *cur){
2      while (cur != NULL){
3          printf("%d\n", cur->item);
4          cur = cur->next;
5      }
6  }
```

```
20
30
60
70
```

HOW TO USE THE LINKED LISTS?



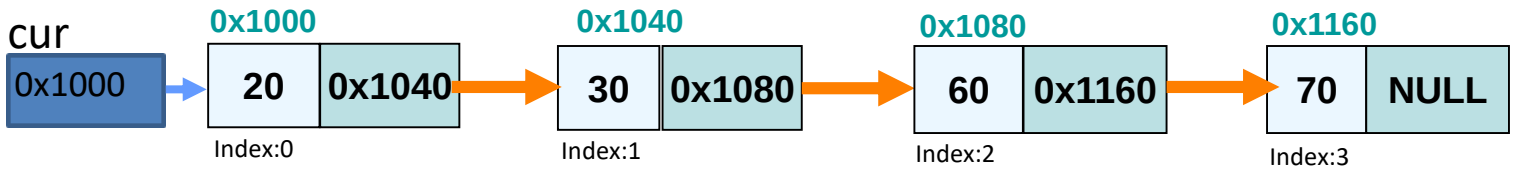
SEARCH: findNode()

```
ListNode* findNode(ListNode *cur, int i);
```

Looking for the i^{th} node in the list

1. **Given the head pointer of the linked list and index *i***
2. **Return the pointer to the i^{th} node**
3. **NULL will be return if index *i* is out of the range or the linked list is empty**

```
1 ListNode *findNode(ListNode* cur, int i)
2 {
3    if (cur==NULL || i<0)
4       return NULL;
5    while(i>0){
6       cur=cur->next;
7       if (cur==NULL)
8          return NULL;
9       i--;
10   }
11   return cur;
12 }
```



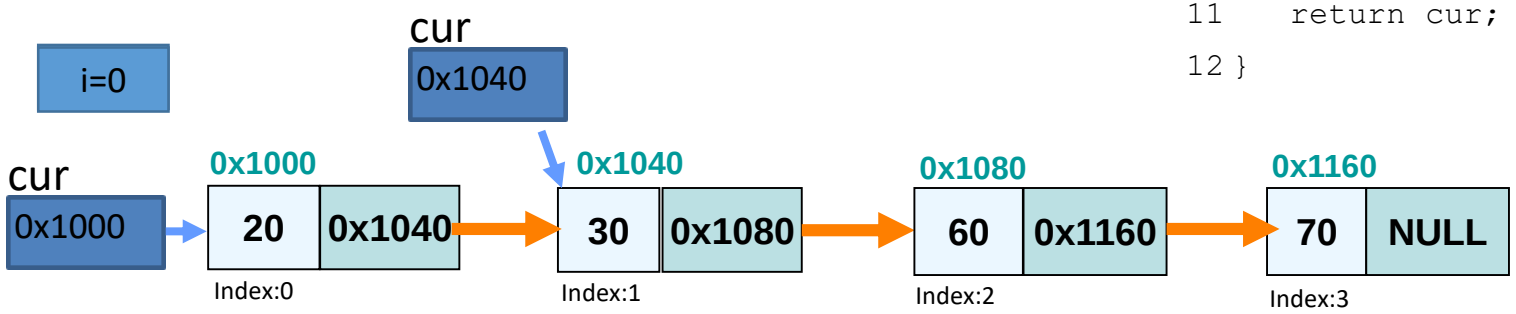
SEARCH: findNode()

```
ListNode* findNode(ListNode *cur, int i);
```

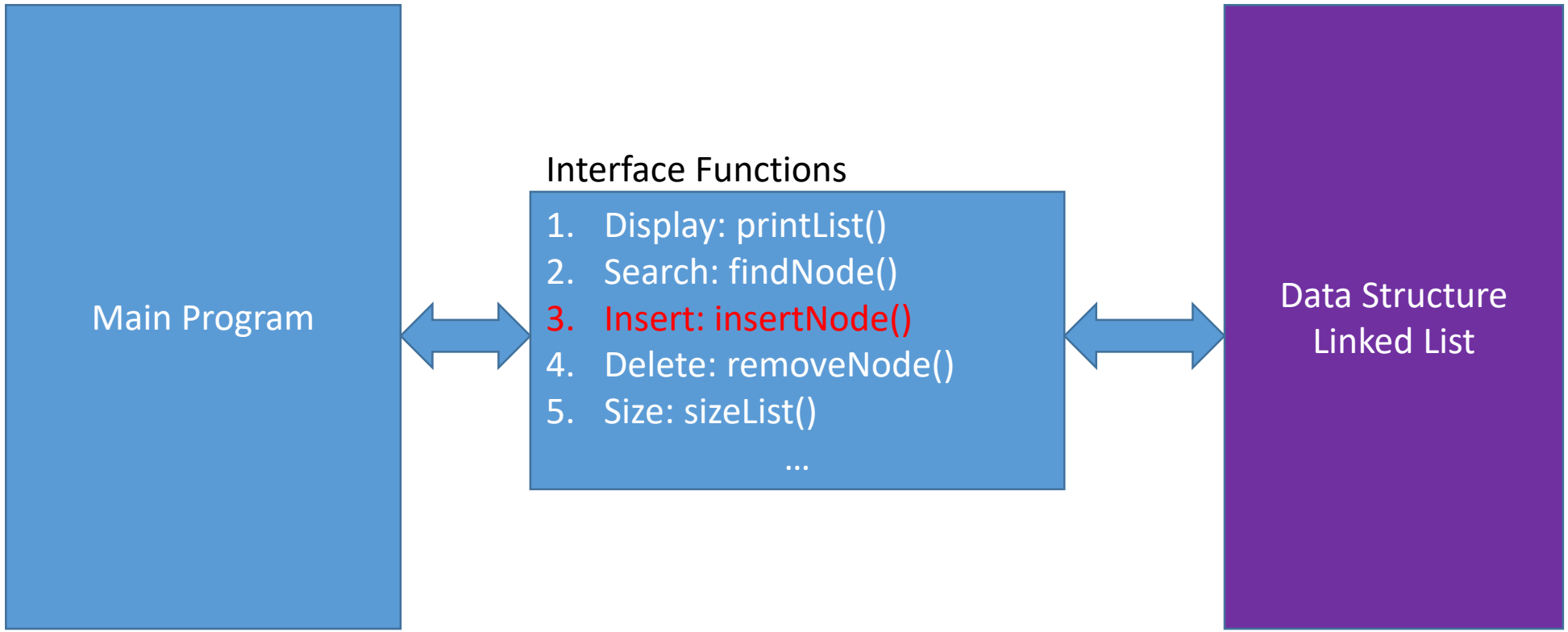
Looking for the *1st* node in the list

1. **Given the head pointer of the linked list and index *i=1***

```
1 ListNode *findNode(ListNode* cur, int i)
2 {
3    if (cur==NULL || i<0)
4       return NULL;
5    while(i>0){
6       cur=cur->next;
7       if (cur==NULL)
8          return NULL;
9       i--;
10   }
11   return cur;
12 }
```



HOW TO USE THE LINKED LISTS?



INSERT: insertNode()

```
int insertNode(ListNode **ptrHead, int i, int item);
```

Add a node in the linked list

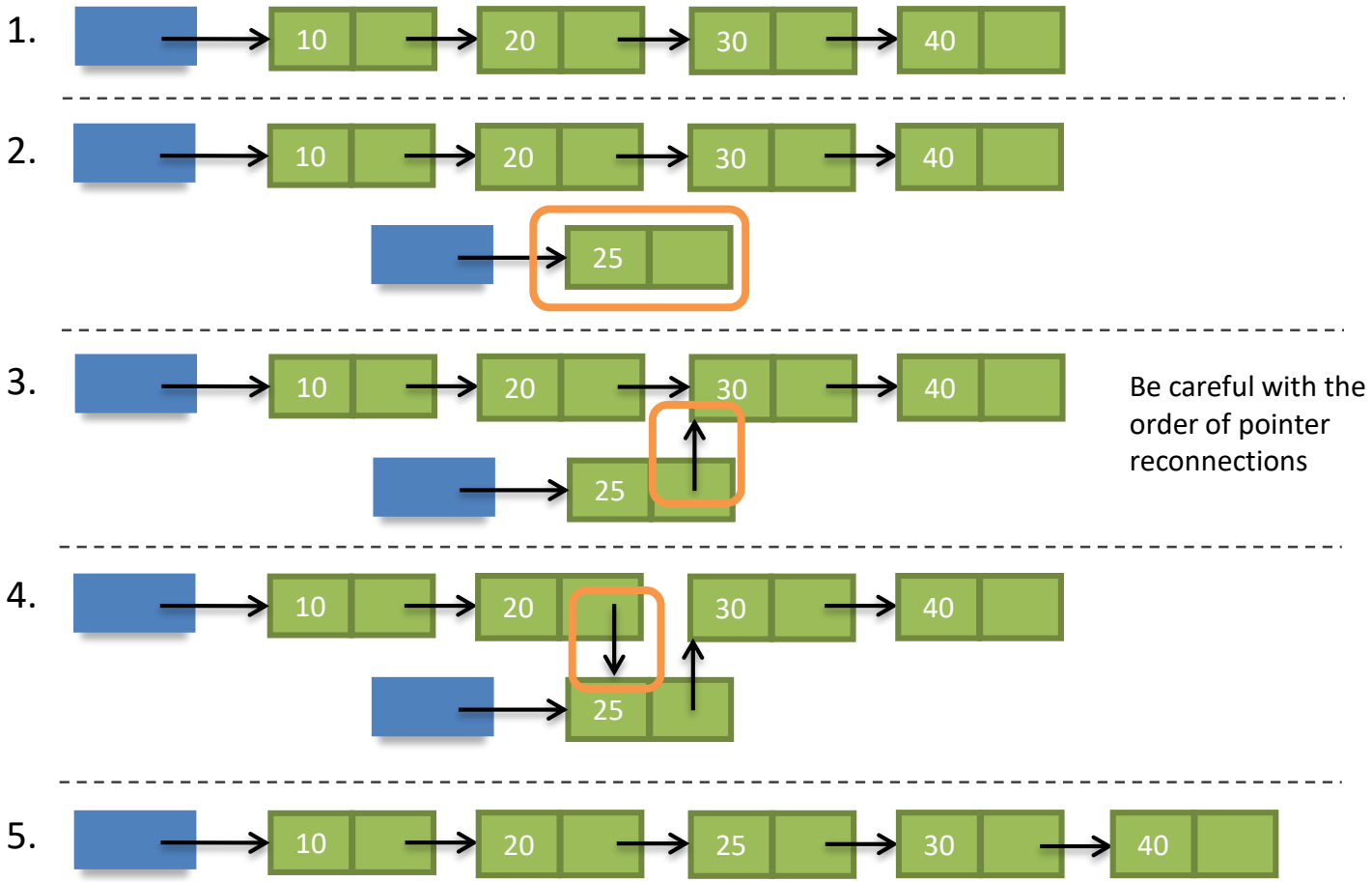
Given

- **the head pointer of the linked list**
- **index *i* where the node to be inserted**
- **the item for the node**

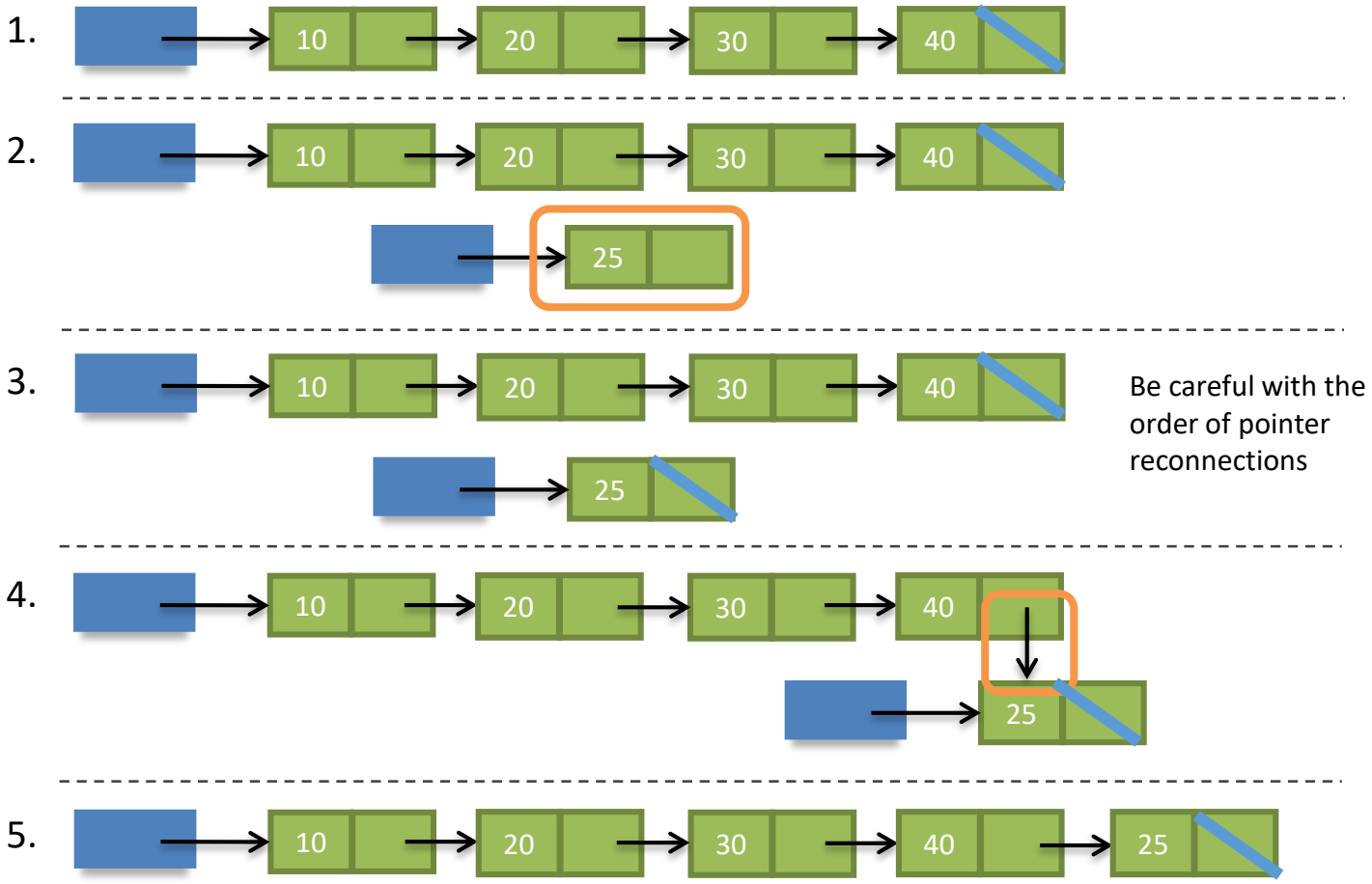
Return SUCCESS (1) or FAILURE (0)

1. **Create a node by the given item**
2. **Insert the node at**
    1. **Front**
    2. **Middle**
    3. **Back**

INSERT A NODE IN MIDDLE



INSERT A NODE IN BACK



INSERT A NODE FRONT

- What is common to both special cases?
  - Empty list

```
head = malloc(sizeof(ListNode))
```

  - Inserting a node at index 0


```
// Save address of the first node
head = malloc(sizeof(ListNode))
head->next = [address of first node]
```

INSERT: insertNode()

```
int insertNode(ListNode **ptrHead, int i, int item);
```

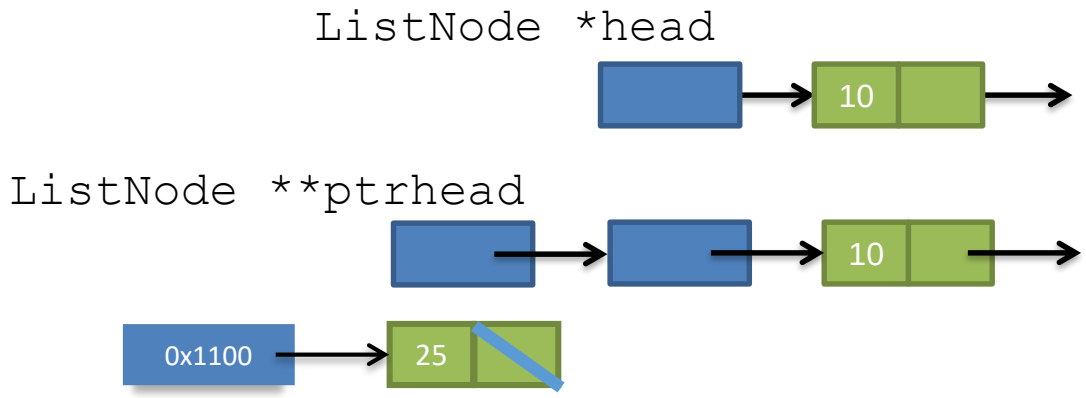
Add a node in the linked list

Given

- **the head pointer of the linked list**
- **index *i* where the node to be inserted**
- **the item for the node**

Return SUCCESS or FAILURE

1. **Create a node by the given item**
2. **Insert the node at**
    1. **Front**
    2. **Middle**
    3. **Back**



Memory Address	Data
0x1000	head=&ListNode 0x1080
0x1060	ptrhead=&head 0x1000
0x1080	item=10 next=0x10c0
0x1100	Item=25 next=NULL

INSERT: insertNode()

```
int insertNode(ListNode **ptrHead, int i, int item);
```

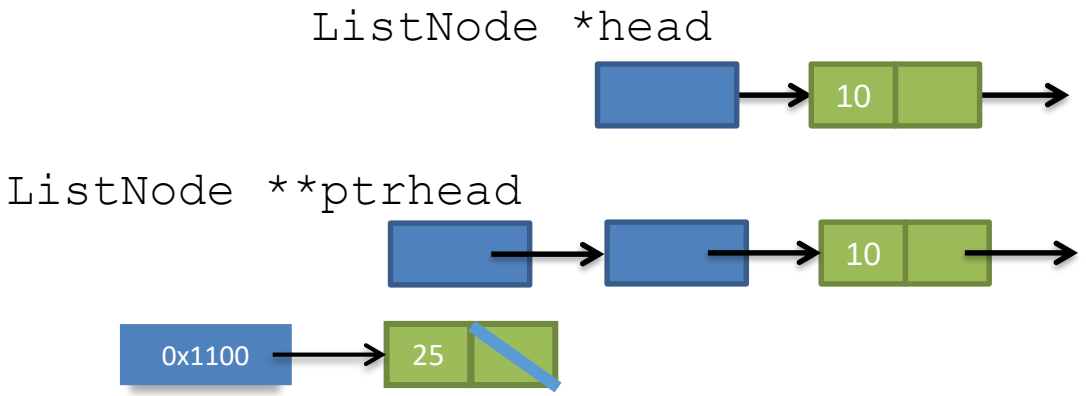
If we only pass head (0x1080) to insertNode(),

we only can access item=10 and next=0x10c0

we cannot modify the content in 0x1000.

When we are back from insertNode() to main(),

0x1000 still remain as 0x1080

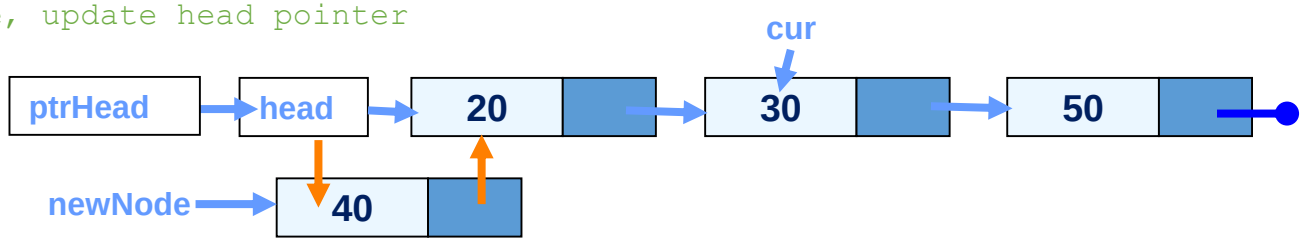


Memory Address	Data
0x1000	head=&ListNode 0x1080
0x1060	ptrhead=&head 0x1000
0x1080	item=10 next=0x10c0
0x1100	item=25 next=NULL

insertNode()

Is there any bug?

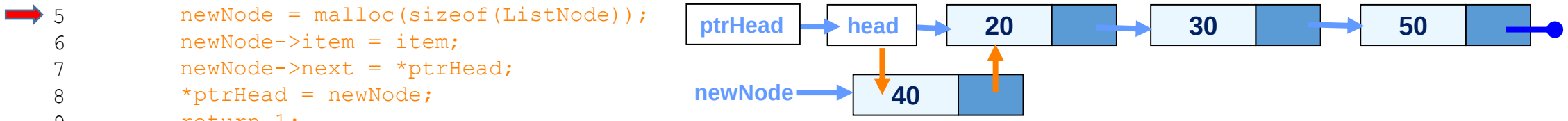
```
1 int insertNode(ListNode **ptrHead, int i, int item){
2     ListNode  *cur, *newNode;
3     // If empty list or inserting first node, update head pointer
4     if (*ptrHead == NULL || i == 0){
5         newNode = malloc(sizeof(ListNode));
6         newNode->item = item;
7         newNode->next = *ptrHead;
8         *ptrHead = newNode;
9         return 1;
10    }
11    // Find the nodes before and at the target position
12    // Create a new node and reconnect the links
13    else if ((cur = findNode(*ptrHead, i-1)) != NULL){
14        newNode = malloc(sizeof(ListNode));
15        newNode->item = item;
16        newNode->next = cur->next;
17        cur->next = newNode;
18        return 1;
19    }
20    return 0;
  }
```



insertNode()

i=0 item=40

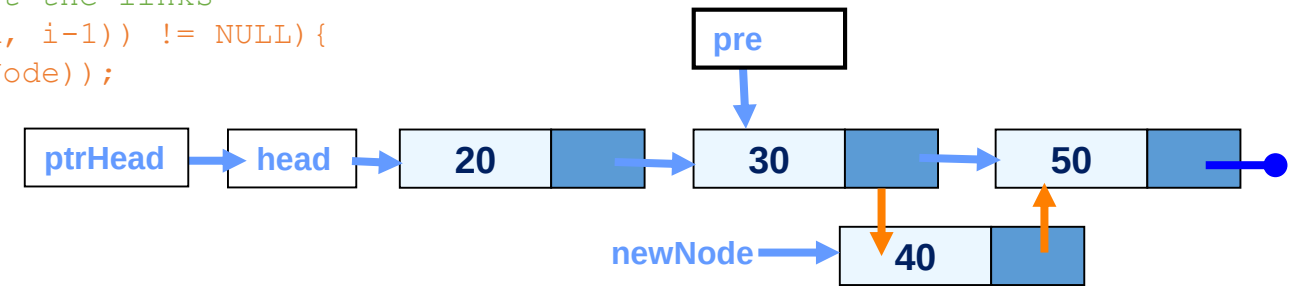
```
1 int insertNode(ListNode **ptrHead, int i, int item){
2     ListNode  *pre, *newNode;
3     // If empty list or inserting first node, update head pointer
4     if (i == 0){
5         newNode = malloc(sizeof(ListNode));
6         newNode->item = item;
7         newNode->next = *ptrHead;
8         *ptrHead = newNode;
9         return 1;
10    }
11    // Find the nodes before and at the target position
12    // Create a new node and reconnect the links
13    else if ((pre = findNode(*ptrHead, i-1)) != NULL){
14        newNode = malloc(sizeof(ListNode));
15        newNode->item = item;
16        newNode->next = pre->next;
17        pre->next = newNode;
18        return 1;
19    }
20    return 0;
  }
```



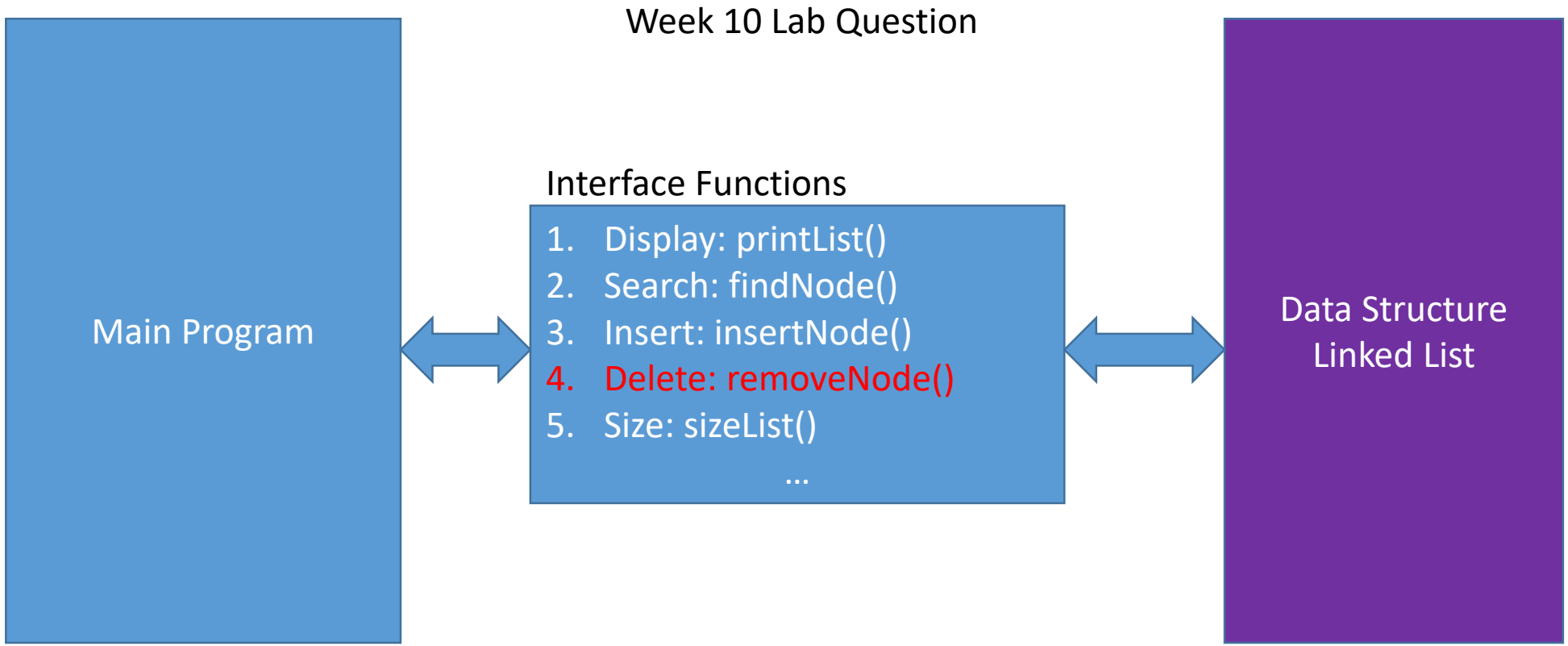
insertNode()

i=2 item=40

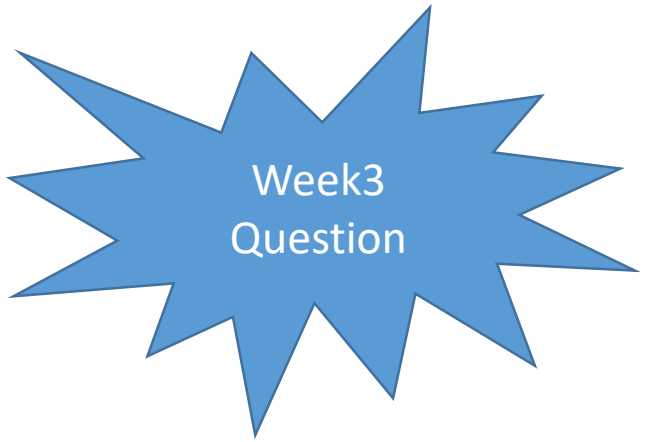
```
 1 int insertNode(ListNode **ptrHead, int i, int item){
 2     ListNode  *pre, *newNode;
 3     // If empty list or inserting first node, update head pointer
 4     if (i == 0){
 5         newNode = malloc(sizeof(ListNode));
 6         newNode->item = item;
 7         newNode->next = *ptrHead;
 8         *ptrHead = newNode;
 9         return 1;
10     }
11     // Find the nodes before and at the target position
12     // Create a new node and reconnect the links
13     else if ((pre = findNode(*ptrHead, i-1)) != NULL){
14         newNode = malloc(sizeof(ListNode));
15         newNode->item = item;
16         newNode->next = pre->next;
17         pre->next = newNode;
18         return 1;
19     }
20     return 0;
   }
```



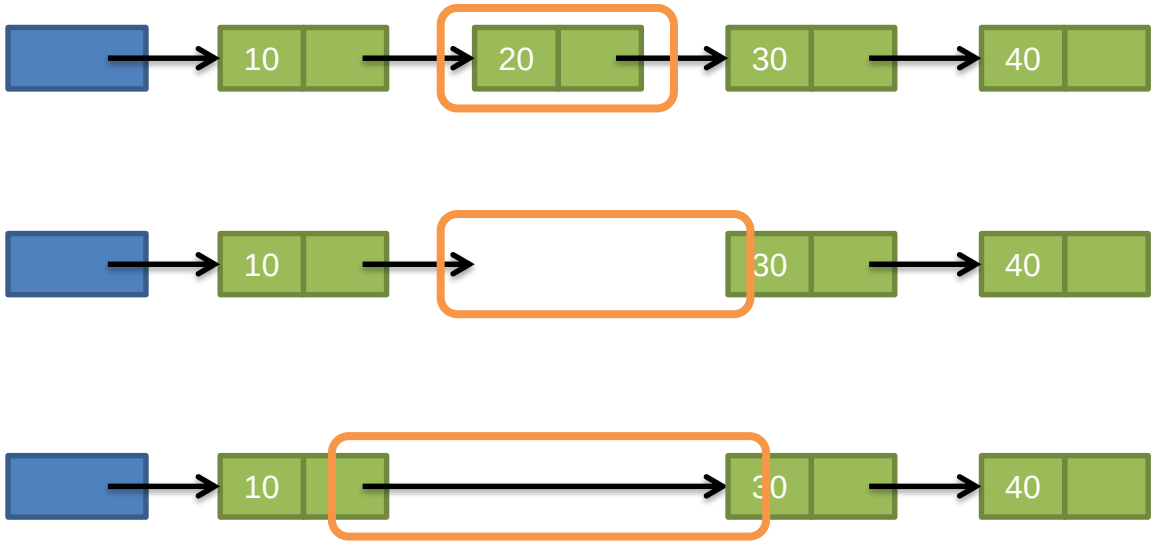
HOW TO USE THE LINKED LIST?



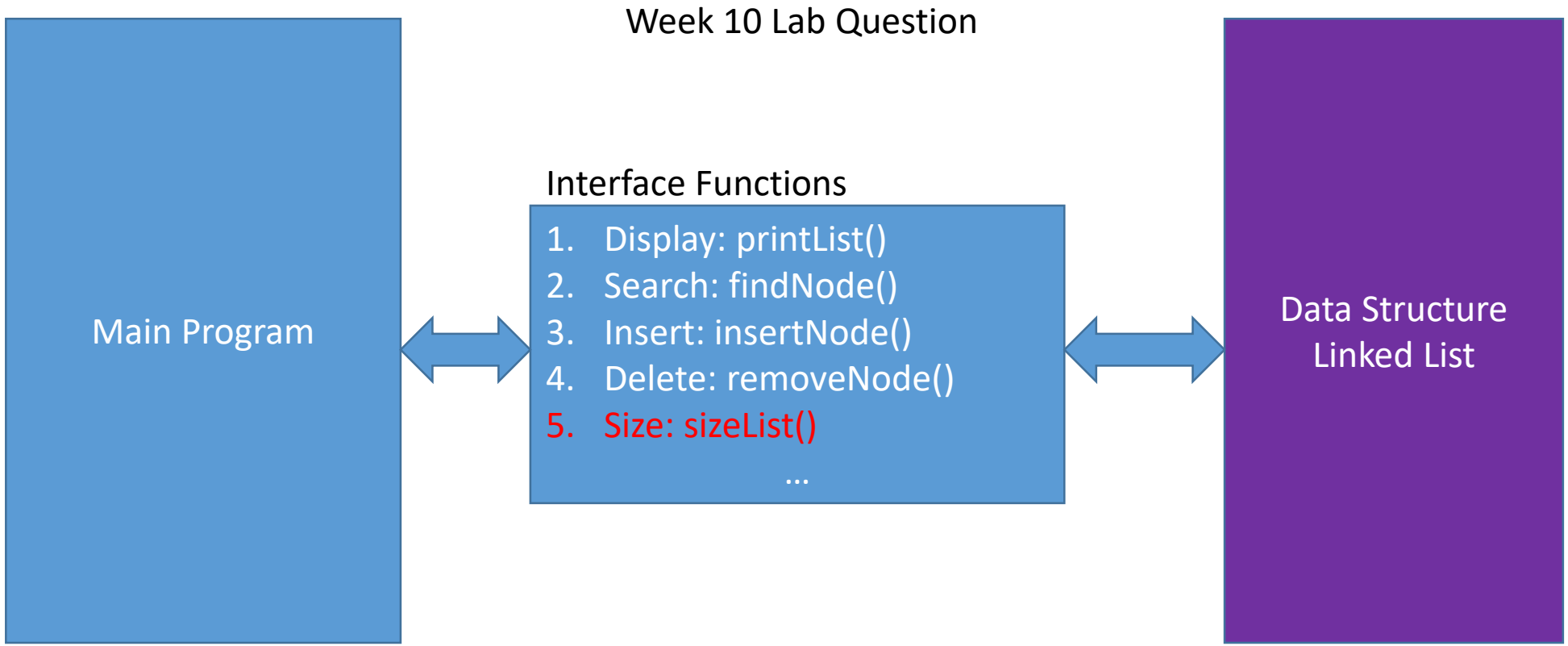
REMOVE A NODE: removeNode()



- Remember to free up any unused memory
- Remove a node at
    1. Front
    2. Middle
    3. Back



HOW TO USE THE LINKED LIST?



SIZE: sizeList()

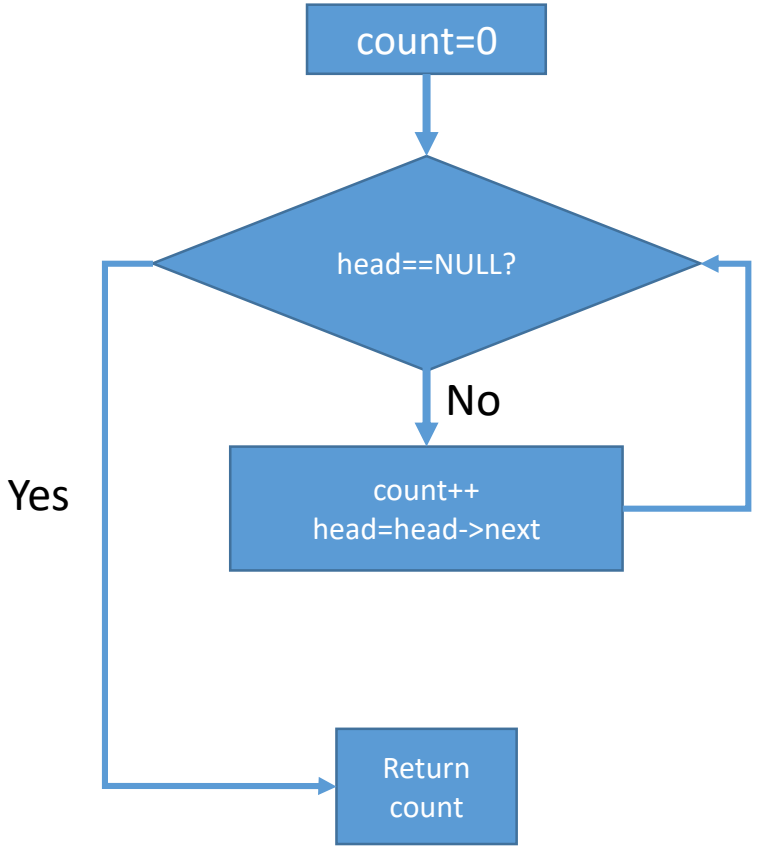
```
int sizeList(ListNode *head);
```

Given

- **the head pointer of the linked list**

Return the number of nodes in the linked list

1. **Declare a counter and initialize it to zero**
2. **Check the pointer whether is NULL or not**
3. **Increase the counter**
4. **Head move to next node**
5. **Repeat step 2**
6. **Return the counter**



SIZE: sizeList()

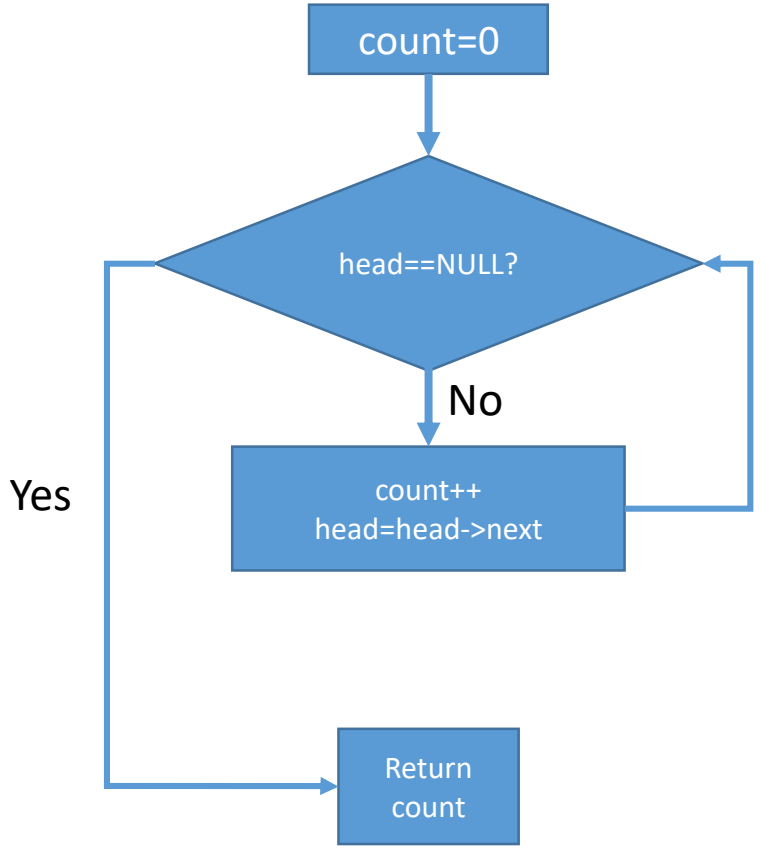
```
int sizeList(ListNode *head);
```

Given

- **the head pointer of the linked list**

Return the number of nodes in the linked list

```
1   int sizeList(ListNode *head){
2
3       int count = 0;
4
5       while (head != NULL){
6           count++;
7           head = head->next;
8       }
9
10      return count;
11  }
```



Why do you need a linked list?

LINKED LIST VS ARRAY

1. **Display: Both are similar**
2. **Search: Array is better**
3. **Insert and Delete: Linked List is more flexible**
4. **Size: Array is better**

Can we improve our sizeList()?

Interface Functions

1. Display: printList()
2. Search: findNode()
3. Insert: insertNode()
4. Delete: removeNode()
5. Size: sizeList()

…

```
1  void printList(ListNode *cur){
2      while (cur != NULL){
3          printf("%d\n", cur->item);
4          cur = cur->next;
5      }
6  }
```

```
1  int sizeList(ListNode *head){
2      int count = 0;
3      while (head != NULL){
4              count++;
5              head = head->next;
6      }
7      return count;
8  }
```

```
1  ListNode *findNode(ListNode* cur, int i){
2     if (cur==NULL || i<0)
3        return NULL;
4     while(i>0){
5        cur=cur->next;
6        if (cur==NULL)
7           return NULL;
8        i--;
9     }
10    return cur;
11 }
```

```
1  int insertNode(ListNode **ptrHead, int i, int item){
2      ListNode  *pre, *newNode;
3      if (i == 0){
4          newNode = malloc(sizeof(ListNode));
5          newNode->item = item;
6          newNode->next = *ptrHead;
7          *ptrHead = newNode;
8          return 1;
9      }
10     else if ((pre = findNode(*ptrHead, i-1)) != NULL){
11         newNode = malloc(sizeof(ListNode));
12         newNode->item = item;
13         newNode->next = pre->next;
14         pre->next = newNode;
15         return 1;
16     }
17     return 0;
18 }
```

ARRAYS VS. LINKED LISTS

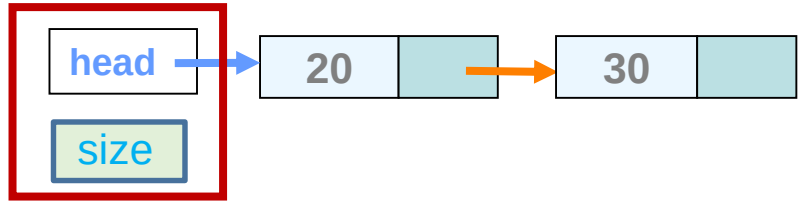
- **Arrays**
  - Efficient random access
  - Difficult to expand, re-arrange
  - When inserting/removing items in the middle or at the front, computation time scales with size of list
  - Generally a better choice when data is immutable
- **Linked lists (dynamic-pointer-based and static-array-based)**
  - “Random access” can be implemented, but more inefficient than arrays
  - cost of storing links, only use internally.
  - Easy to shrink, rearrange and expand (but array-based linked list has a fixed size)
  - Insert/remove operations only require fixed number of operations regardless of list size. no shifting
- Know when to choose an array vs a linked list

CAN WE IMPROVE OUR sizeList()?

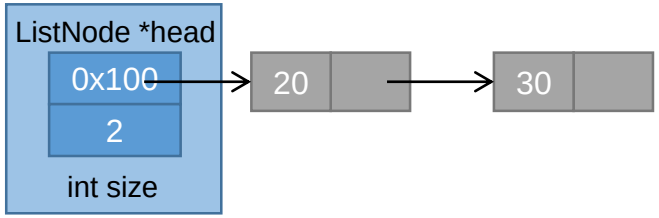
```
1  int sizeList(ListNode *head){
2      int count = 0;
3      while (head != NULL){
4              count++;
5              head = head->next;
6      }
7      return count;
8  }
```

- Solution:
  - Define another C struct, LinkedList
  - Wrap up all elements that are required to implement the Linked List data structure

```
typedef struct _linkedlist{
    ListNode *head;
    int size;
} LinkedList;
```




```
1  int sizeList(LinkedList ll){
2      return ll.size;
3  }
```



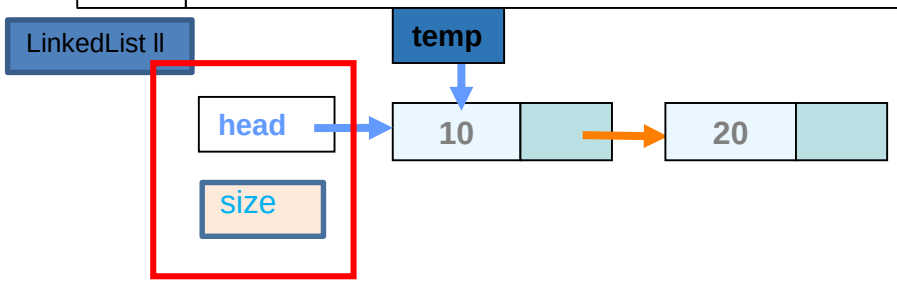
- Remember to change size when adding/removing nodes

LINKED LIST FUNCTIONS USING LinkedList STRUCT

- Original function prototypes:
  - void printList(ListNode *head);
  - ListNode *findNode(ListNode *head);
  - int insertNode(ListNode **ptrHead, int i, int item);
  - int removeNode(ListNode **ptrHead, int i);
- New function prototypes:
  - **void printList(LinkedList ll);**
  - **ListNode *findNode(LinkedList ll, int i);**
  - **int insertNode(LinkedList *ll, int index, int item);**
  - **int removeNode(LinkedList *ll, int i);**

NEW printList()

```
1  void printList(ListNode *cur){
2      while (cur != NULL){
3          printf("%d\n", cur->item);
4          cur = cur->next;
5      }
6  }
```




```
typedef struct _linkedlist{
   ListNode *head;
   int size;
}LinkedList;
```

```
1  void printList(LinkedList ll){
2      ListNode *temp = ll.head;
3
4      while (temp != NULL){
5          printf("%d\n", temp->item);
6          temp = temp->next;
7      }
8  }
```

NEW findNode()

```
typedef struct _linkedlist{
   ListNode *head;
   int size;
}LinkedList;
```

```
1  ListNode *findNode(ListNode* cur, int i){
2     if (cur==NULL || i<0)
3        return NULL;
4     while(i>0){
5        cur=cur->next;
6        if (cur==NULL)
7           return NULL;
8        i--;
9     }
10    return cur;
11 }
```

```
1  ListNode *findNode(LinkedList ll, int i){
2      ListNode *temp = ll.head;
3      if (cur==NULL || i < 0|| i >ll.size)
4          return NULL;
5
6      while (i > 0){
7          temp = temp->next;
8          if (temp == NULL)
9              return NULL;
10         i--;
11     }
12     return temp;
13 }
```

HOMEWORK

```
typedef struct _linkedlist{
   ListNode *head;
   int size;
}LinkedList;
```

```
 1  int insertNode(ListNode **ptrHead, int i, int item){
 2      ListNode  *pre, *newNode;
 3      if (i == 0){
 4          newNode = malloc(sizeof(ListNode));
 5          newNode->item = item;
 6          newNode->next = *ptrHead;
 7          *ptrHead = newNode;
 8          return 1;
 9      }
10      else if ((pre = findNode(*ptrHead, i-1)) != NULL){
11          newNode = malloc(sizeof(ListNode));
12          newNode->item = item;
13          newNode->next = pre->next;
14          pre->next = newNode;
15          return 1;
16      }
17      return 0;
18  }
```

```
 1  int insertNode(LinkedList *ll, int i, int item){
 2
 3
 4
 5
 6
 7
 8
 9
10
11
12
13
14
15
16
17
18  }
```