NANYANG TECHNOLOGICAL UNIVERSITY
SINGAPORE

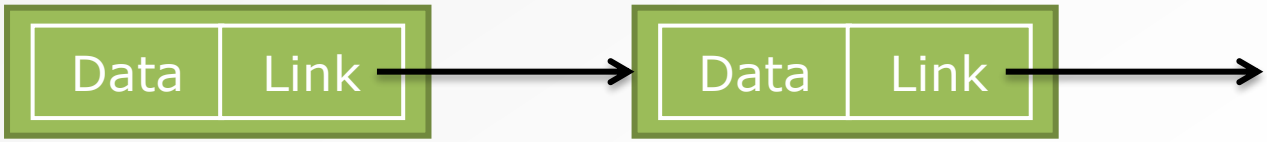
CE1107/CZ1107: DATA STRUCTURES AND ALGORITHMS

Lecture 3: **Linked List Functions**

College of Engineering
School of Computer Science and Engineering

BASIC LINKED LIST NODES

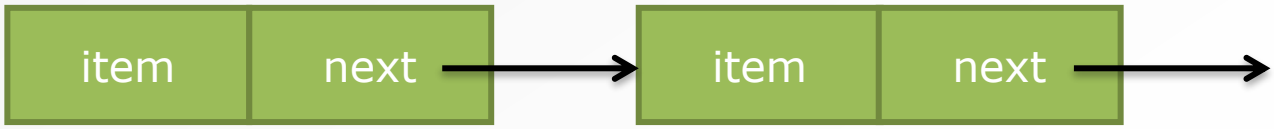
- Each node is a ListNode structure
- Basic nodes have two components:
  - Data stored in that node
  - Link to the next node in the sequence



BASIC LINKED LIST NODES

- Basic node structure
- For now, assume that a node stores an integer

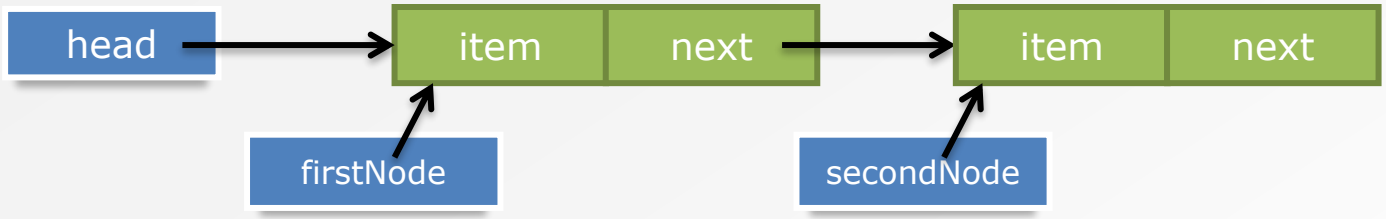
```
typedef struct _listnode{
    int item;
    struct _listnode * next;
} ListNode;
```



LINKED LIST OF NODES

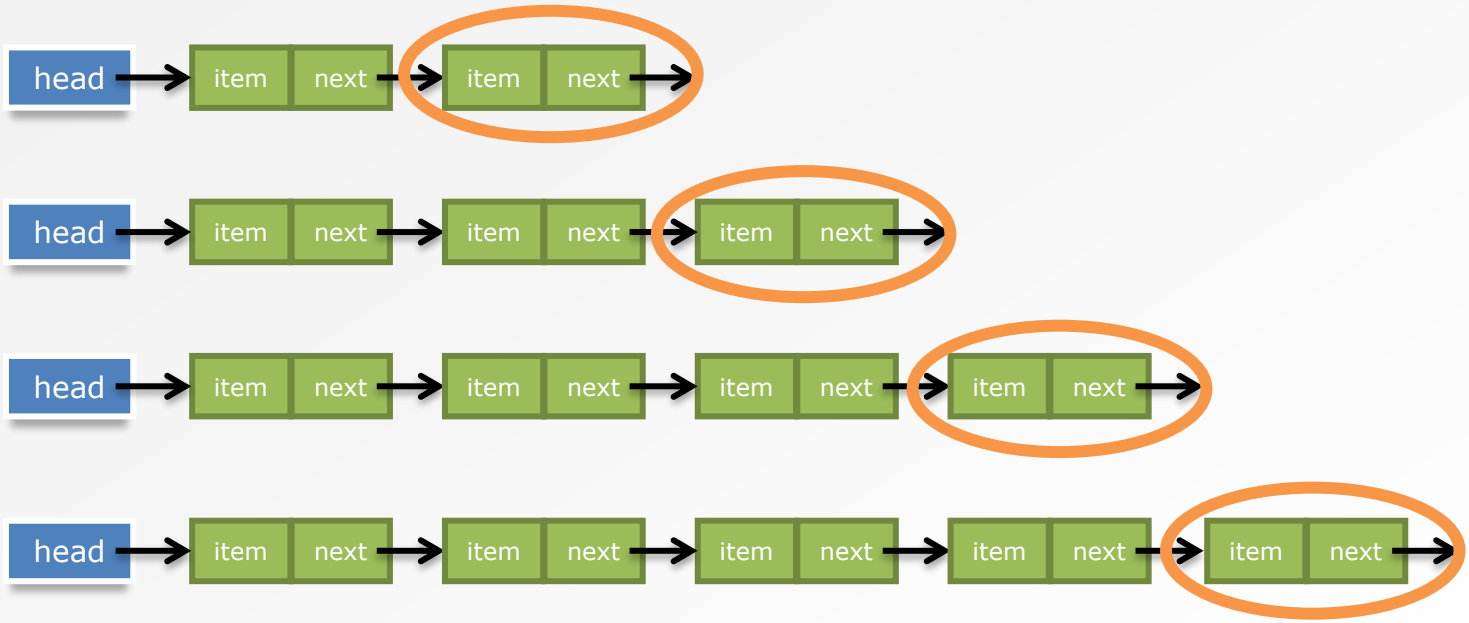
- Without the address of the first node, everything else is inaccessible
- Add a pointer variable ***head*** to save the address of the first ListNode struct
- What is the data type for head?

SINGLY-LINKED LIST OF INTEGERS (TWO NODES)



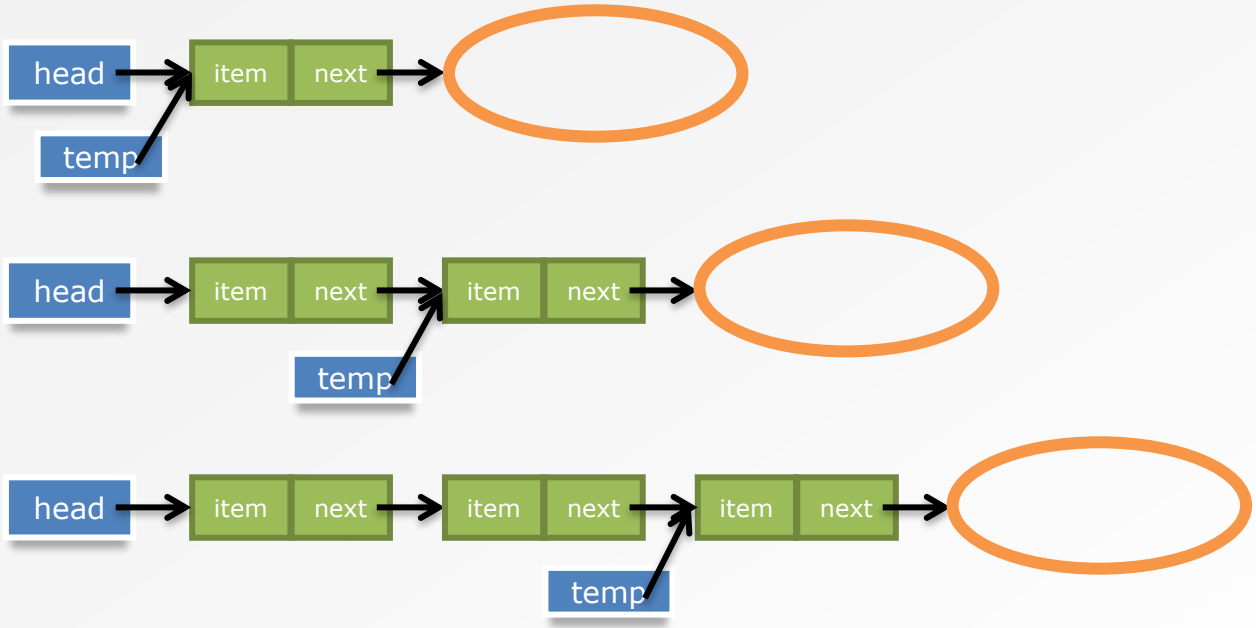

```
1    typedef struct node{
2            int item;
3            struct node *next;
4    } ListNode;
5
6    int main(){
7            ListNode *head, *firstNode, *secondNode;
8
9            firstNode = malloc(sizeof(ListNode));
10           secondNode = malloc(sizeof(ListNode));
11
12           head = firstNode;
13           firstNode->next = secondNode;
14           secondNode->next = NULL;
15   }
```

BACK TO LAB QUESTION: STORE A LIST OF NUMBERS



- Address of each new ListNode is saved in next pointer of previous node
- Need a way to keep track of the last ListNode at any time
  - Use another pointer variable

BACK TO LAB QUESTION: STORE A LIST OF NUMBERS

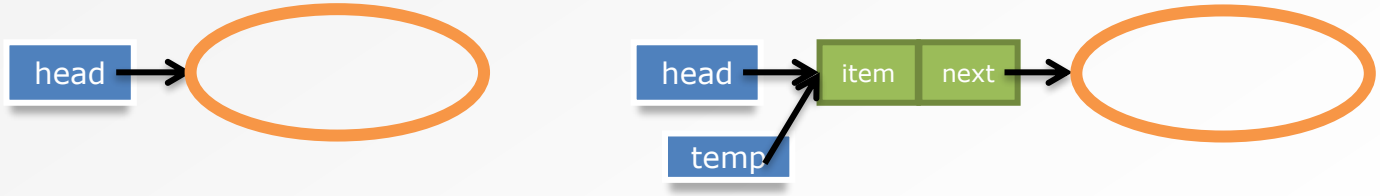


- *temp* pointer stores address of the last ListNode at any time
- Create a new ListNode

```
temp->next = malloc(sizeof(ListNode));
```

BACK TO PREVIOUS QUESTION: STORE A LIST OF NUMBERS

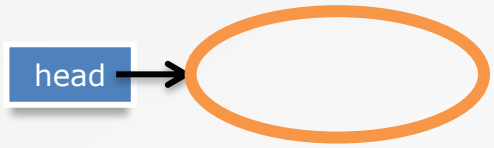
- After the first ListNode has been created
  - *head* pointer points to first ListNode
  - Can now use *temp* pointer to keep track of last node
  - In this case, *temp* also points to the first ListNode



BACK TO LAB QUESTION: STORE A LIST OF NUMBERS

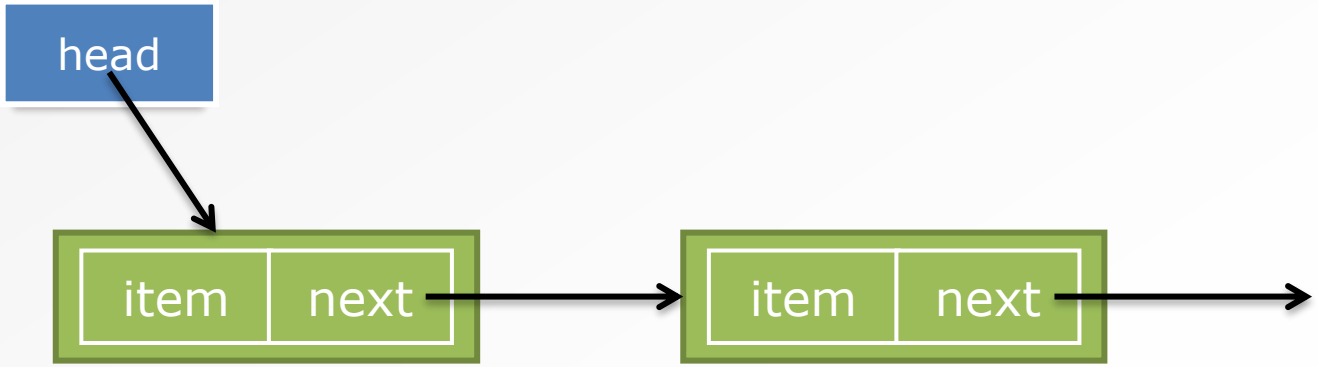
- Watch out for special case
  - First node in the linked list
  - *head* == NULL
  - Need to update the *head* pointer

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



COMMON MISTAKES

- **Very important!**
  - *head* is a node pointer
  - Points to the first node
  - *head* is not the "first node"
  - *head* is not the "head node"



TODAY

- ListNode structures
- Core linked list data structure functions
  - printList();
  - findNode();
  - insertNode()
  - removeNode()
- Common mistakes

LEARNING OBJECTIVES

After this lesson, you should be able to:

- Describe and implement the core linked list functions
  - Draw the diagrams for each step
  - Write pseudocode (if necessary)
  - Write C code to implement the functions
- Carry out the same process for any linked list function

IMPLEMENT DATA STRUCTURE FUNCTIONS WITHOUT MEMORY LEAKS AND ILLEGAL ACCESS ERRORS

- Concept before code
  - Draw all the pictures, step by step
  - Write all the pseudocode (if necessary)
  - Code comes last
  - You should be able to use all the diagrams or pseudocode to implement a linked list in any language

TODAY

- **ListNode structures**
- Core linked list data structure functions
  - printList();
  - findNode();
  - insertNode()
  - removeNode()
- Common mistakes

RECALL: ListNode STRUCTURE

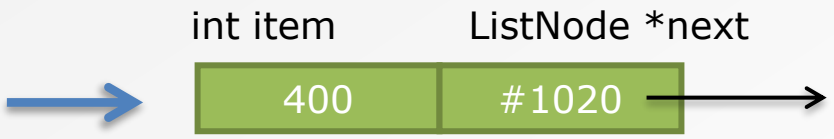
- Our default ListNode for the rest of the class will store an integer item

```
typedef struct _listnode{
      int item;
      struct _listnode * next;
  } ListNode;
```

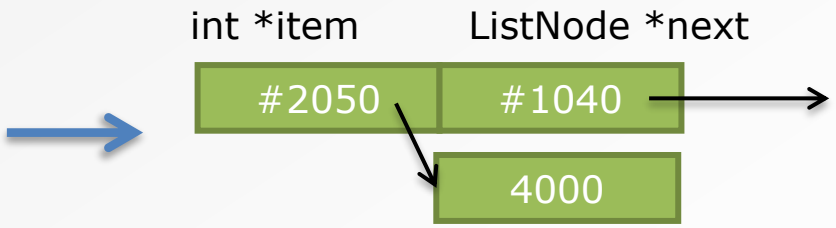
- ListNodes can store anything in the item field
  - int or int*
  - Array of integers
  - char or char*
  - Another struct or a pointer to a struct
  - Whatever you want
  - Can even define int item1, item2

ADVANCED ListNode STRUCTURES

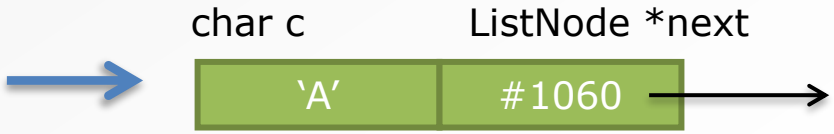
```
typedef struct _listnode{
    int item;
    struct _listnode *next;
} ListNode;
```




```
typedef struct _listnode{
    int *item;
    struct _listnode *next;
} ListNode;
```




```
typedef struct _listnode{
    char c;
    struct _listnode *next;
} ListNode;
```

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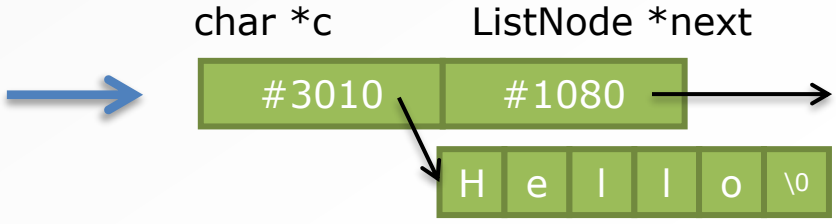
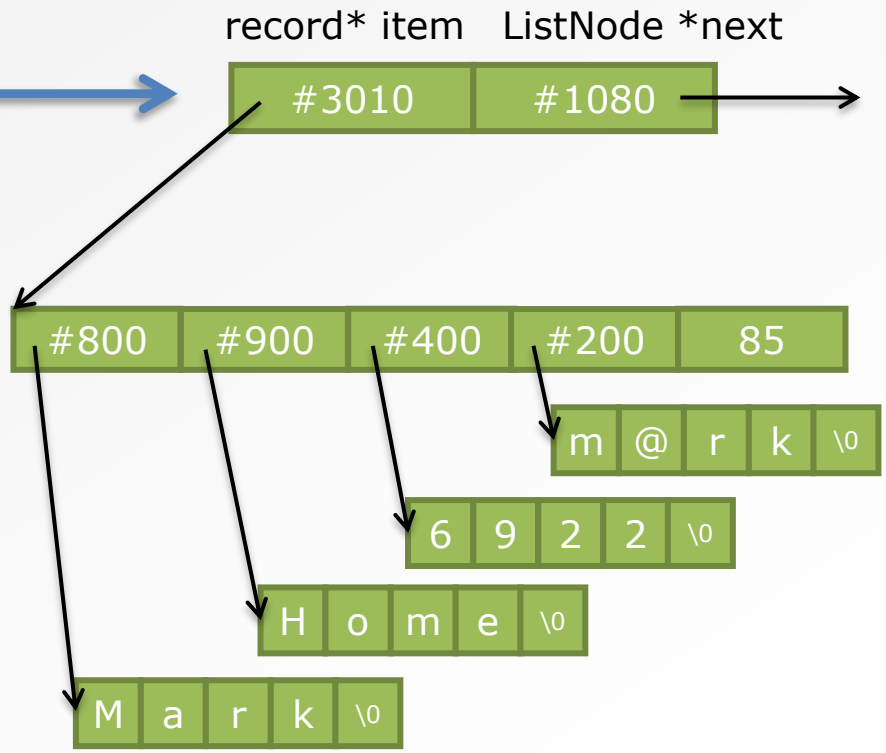
typedef struct _listnode{
    char *c;
    struct _listnode *next;
} ListNode;
```



ADVANCED ListNode STRUCTURES

```
typedef struct _listnode{
    struct record *item;
    struct _listnode *next;
} ListNode;
```




```
struct record{
    char *name;
    char *address;
    char *phone
    char *email
    int age;
}
```

TODAY

- ListNode structures
- **Core linked list data structure functions**
  - printList();
  - findNode();
  - insertNode()
  - removeNode()
- Common mistakes

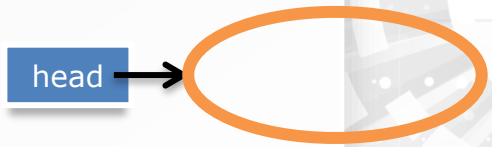
SINGLY-LINKED LIST OF INTEGERS

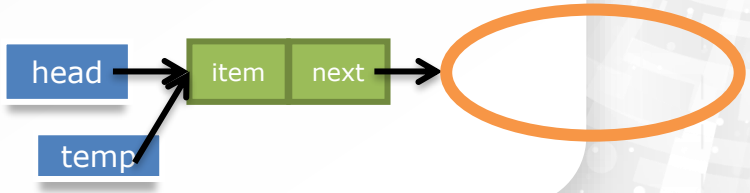
```
1  typedef struct node{
2      int item;  struct node *next;
3  } ListNode;
4
5  int main(){
6      ListNode *head = NULL, *temp;
7      int i = 0;
8
9      scanf("%d", &i);
10     while (i != -1){
11         if (head == NULL){
12             head = malloc(sizeof(ListNode));
13             temp = head;
14         }
15         else{
16             temp->next = malloc(sizeof(ListNode));
17             temp = temp->next;
18         }
19         temp->item = i;
20         scanf("%d", &i);
21     }
22     temp->next = null;
23 }
```

Quite silly to do this manually every time

Also, this code can only add to the back of a list

Write a function to add a node (other functions too)





LINKED LIST FUNCTIONS

- Our linked list should support some basic operations
  - Inserting a node — `insertNode()`
    - At the front
    - At the back
    - In the middle
  - Removing a node — `removeNode()`
    - At the front
    - At the back
    - In the middle
  - Printing the whole list — `printList()`
  - Looking for the node at index n — `findNode()`
  - Etc.

TODAY

- ListNode structures
- Core linked list data structure functions
  - **printList();**
  - findNode();
  - insertNode()
  - removeNode()
- Common mistakes

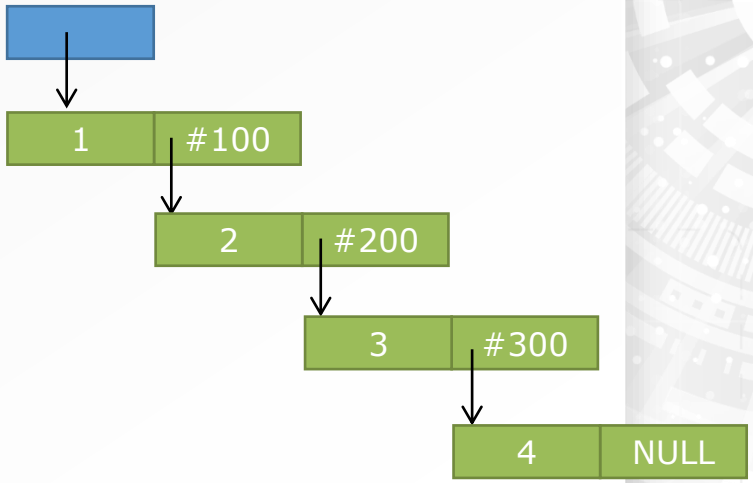
PRINT OUT ITEMS IN LINKED LIST: printList()

- Print all the items by starting from the first node and traversing the list till the end is reached
- Pass head pointer into the function

```
void printList (ListNode *head)
```

  - At each node, use the next pointer to move to the next node

```
1   void printList(ListNode *head){
2
3       if (head == NULL)
4           return;
5
6       while (head != NULL){
7           printf("%d ", head->item);
8           head = head->next;
9       }
10      printf("\n");
11  }
```



PRINT OUT ITEMS IN LINKED LIST: printList() [Version 01]

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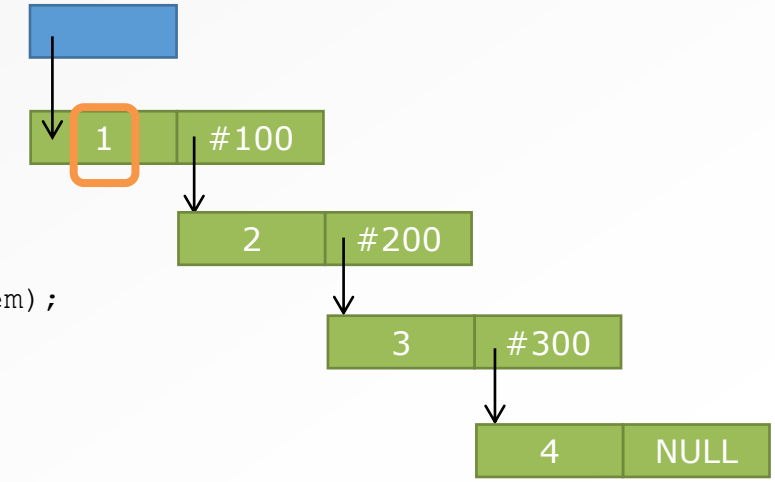

Print: 1

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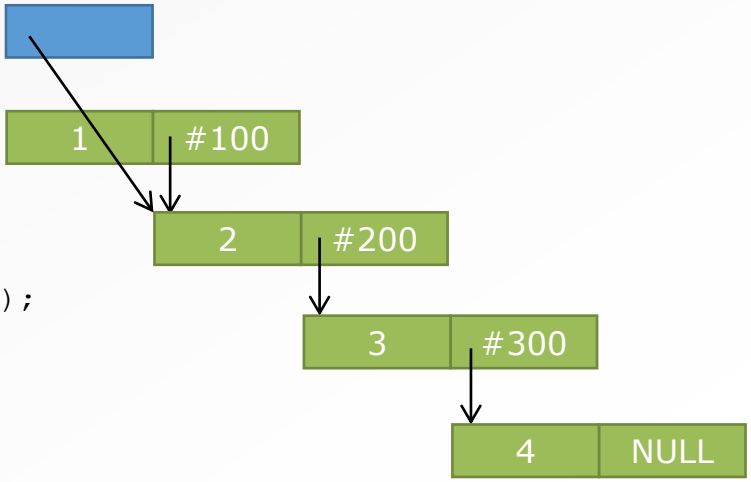

Print: 1

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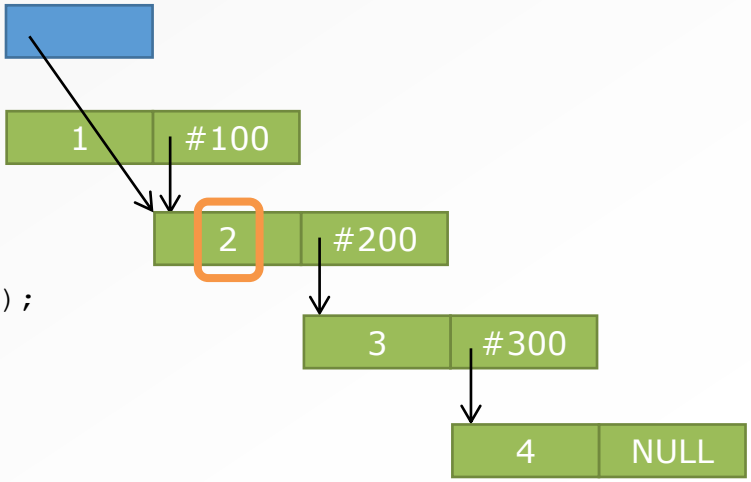

Print: 1 2

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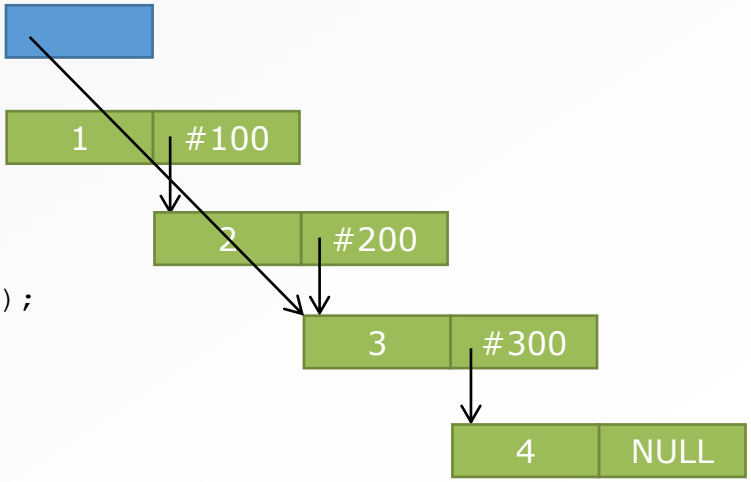
```



Print: 1 2

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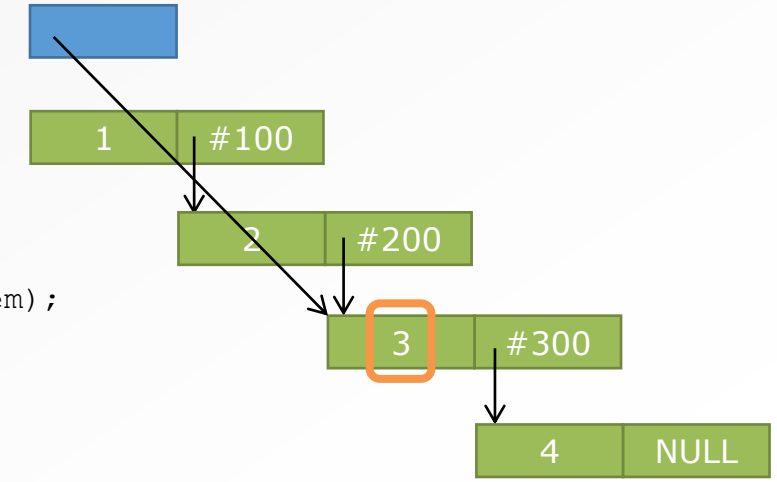
9       }
10      printf("\n");
11  }
```



Print: 1 2 3

PRINT OUT ITEMS IN LINKED LIST: printList() [Version 01]

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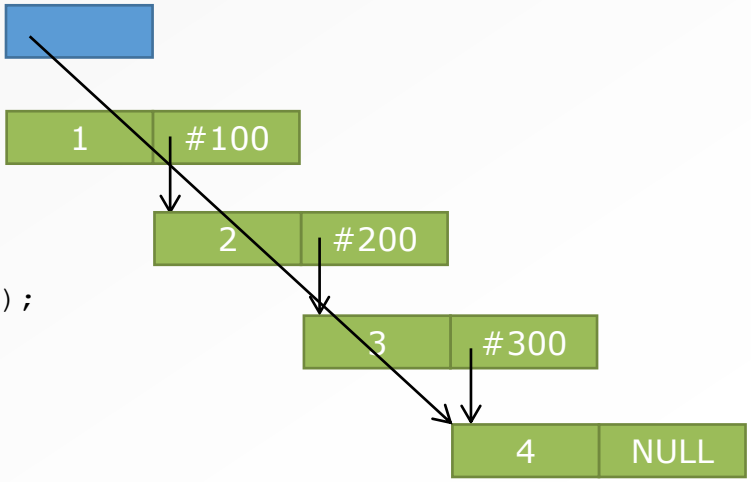
10      printf("\n");
11  }
```



Print: 1 2 3

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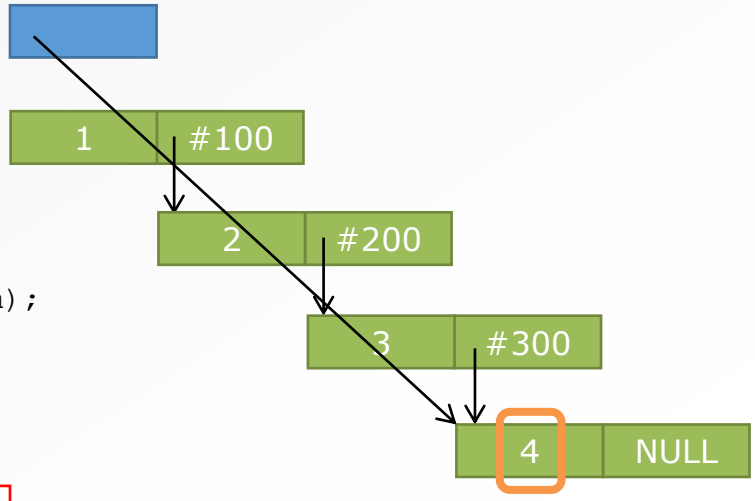
```



Print: 1 2 3 4

PRINT OUT ITEMS IN LINKED LIST: printList() [Version 01]

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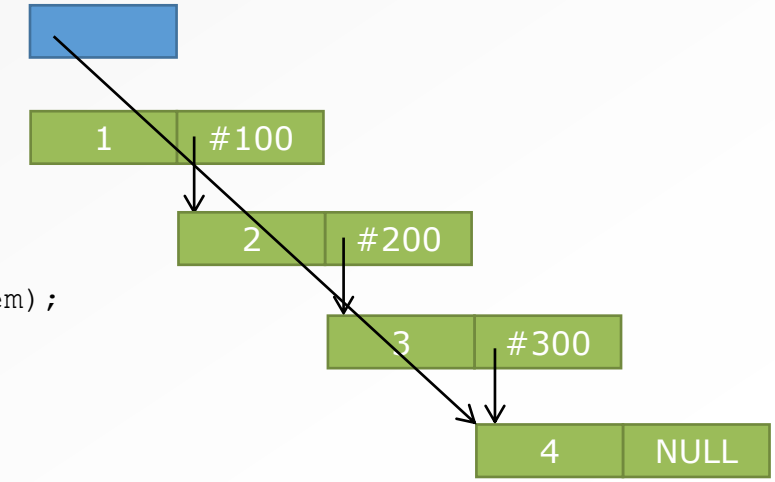

Print: 1 2 3 4

PRINT OUT ITEMS IN LINKED LIST: printList() [Version 01]

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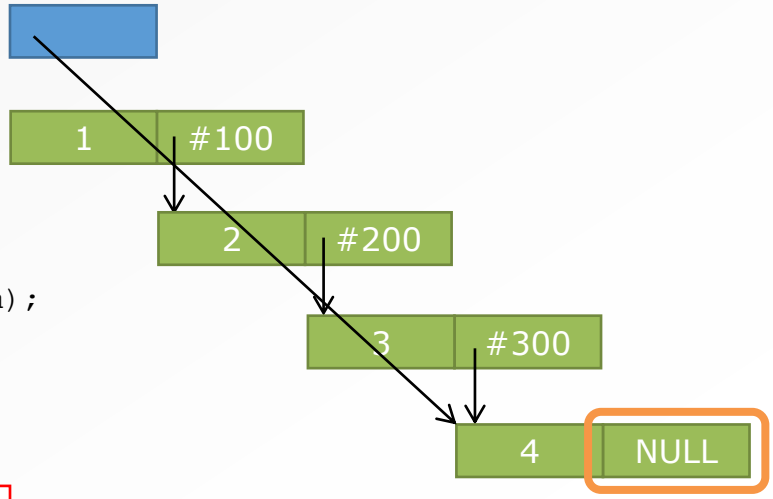

Print: 1 2 3 4

PRINT OUT ITEMS IN LINKED LIST: printList() [Version 01]

- Print all the items by starting from the first node and traversing the list till the end is reached
- Pass head pointer into the function

```
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  - At each node, use the next pointer to move to the next node

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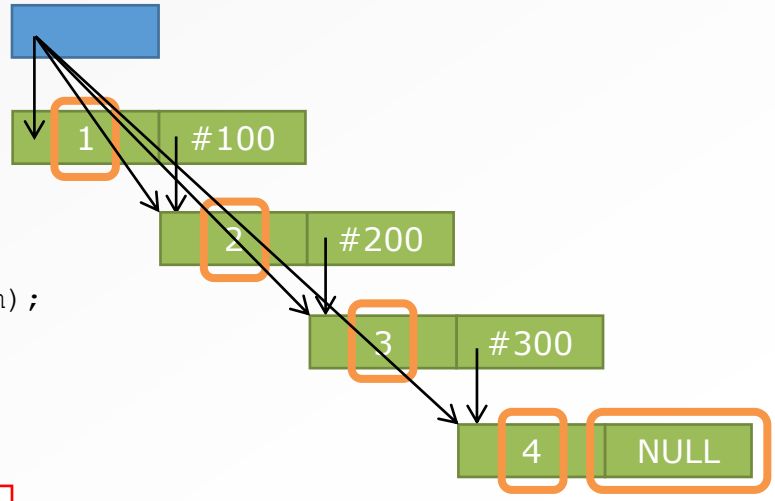


Print: 1 2 3 4

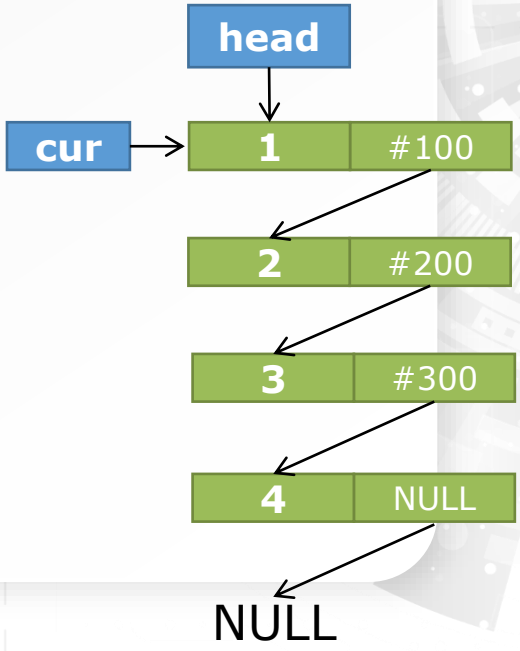
PRINT OUT ITEMS IN LINKED LIST: printList() [Version 02]

- Print all the items by starting from the first node and traversing the list till the end is reached
- Pass head pointer into the function

```
void printList (ListNode *head)
```

  - At each node, use the next pointer to move to the next node

```
1   void printList(ListNode *head){
2       ListNode *cur
3       cur=head;
4       if (cur== NULL)    return;
5
6       while (cur!= NULL){
7           printf("%d\n", cur ->item);
8           cur = cur ->next;
9       }
10      printf("\n");
11  }
```



Print: 1 2 3 4

TODAY

- ListNode structures
- Core linked list data structure functions
  - printList();
  - **findNode();**
  - insertNode()
  - removeNode()
- Common mistakes

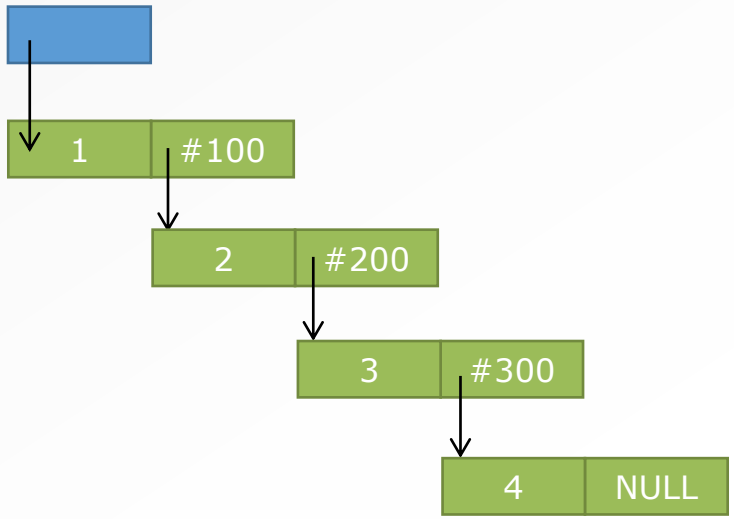
GET POINTER TO NODE AT INDEX i: findNode() [Version 01]

- This function will come in useful later
- Pass head pointer into the function

```
ListNode * findNode(ListNode *head, int index)
```

- Count down *index* times (let's try index = 2)
  - To get to index 2 (the 3rd node), we need to follow 2 next pointers

```
1   ListNode * findNode(
2       ListNode *head, int index){
3
4       if (head == NULL || index < 0)
5           return NULL;
6
7       while (index > 0){
8           head = head->next;
9           if (head == NULL)
10              return NULL;
11          index--;
12      }
13      return head;
14  }
```



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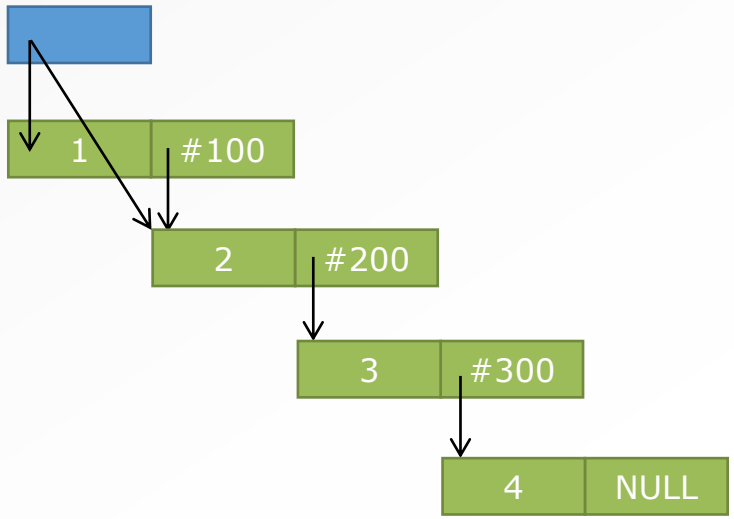
6
7       while (index > 0){
8           head = head->next;
9           if (head == NULL)
10              return NULL;
11          index--;
12      }
13      return head;
14  }
```



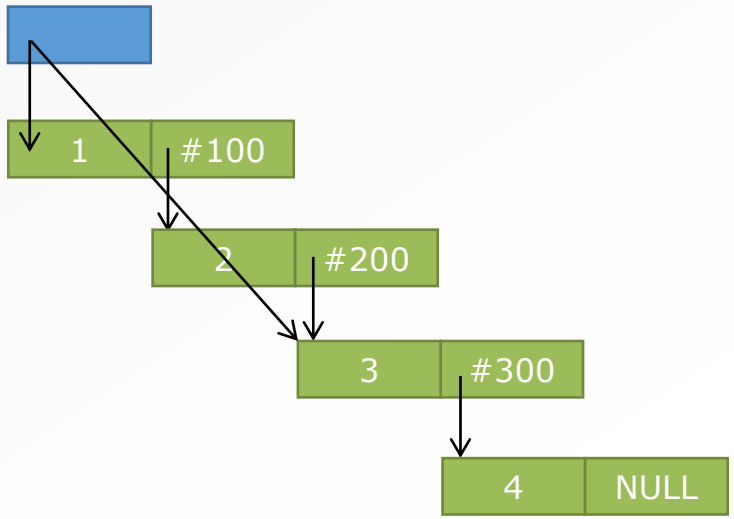
GET POINTER TO NODE AT INDEX i: findNode() [Version 01]

- This function will come in useful later
- Pass head pointer into the function

```
ListNode * findNode(ListNode *head, int index)
```

- Count down *index* times (let's try index = 2)
  - To get to index 2 (the 3rd node), we need to follow 2 next pointers

```
1   ListNode * findNode(
2       ListNode *head, int index){
3
4       if (head == NULL || index < 0)
5           return NULL;
6
7       while (index > 0){
8           head = head->next;
9           if (head == NULL)
10              return NULL;
11          index--;
12      }
13      return head;
14  }
```



GET POINTER TO NODE AT INDEX i: findNode() [Version 02]

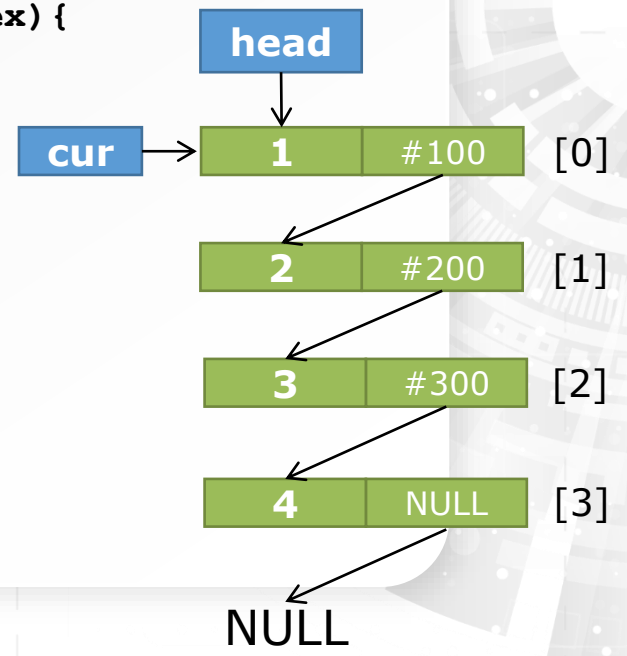
- This function will come in useful later
- Pass head pointer into the function

```
ListNode * findNode(ListNode *head, int index)
```

- Count down *index* times (let's try index = 2)
  - To get to index 2 (the 3rd node), we need to follow 2 next pointers

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

Index = 0



TODAY

- ListNode structures
- Core linked list data structure functions
  - printList();
  - findNode();
  - **insertNode()**
  - removeNode()
- Common mistakes

INSERT A NODE: insertNode()

- Add a node anywhere in the linked list
- Let's work through the process of adding a node
- Have to consider various special cases
- Pass in the head pointer
- What is the correct parameter list?

```
void insertNode(          )
```

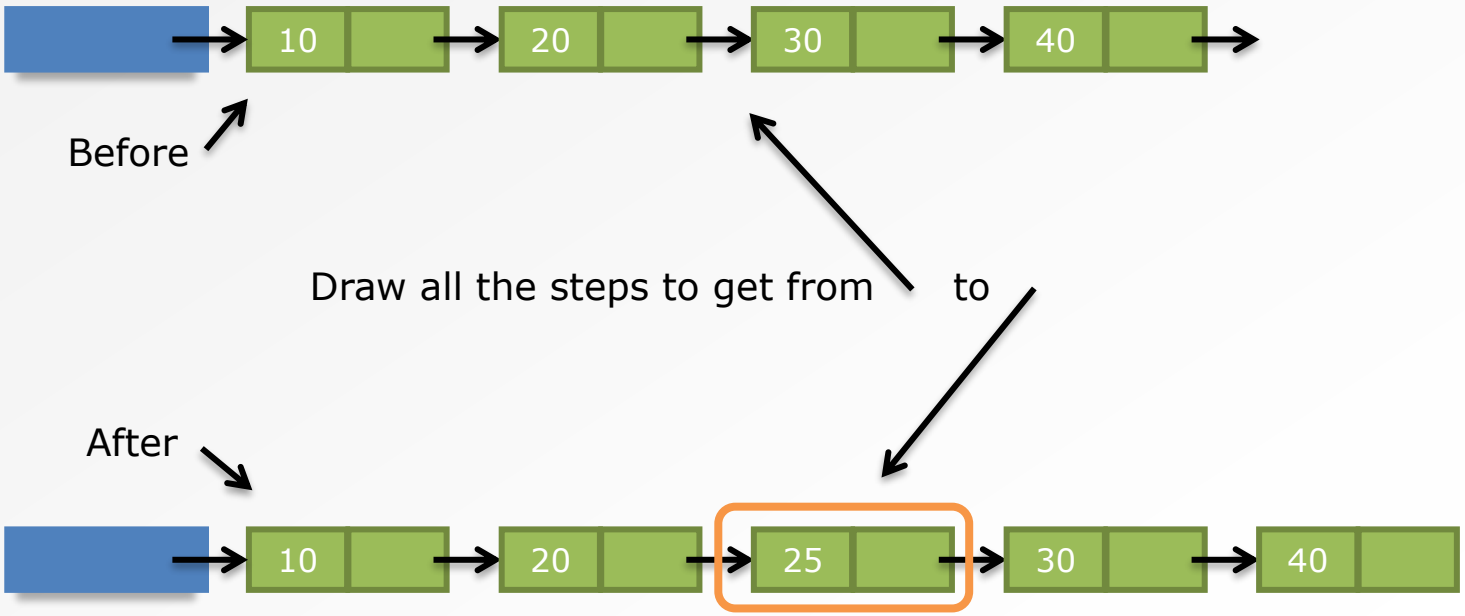
  - KIV – this will become obvious later
  - There is an apparently correct but actually wrong answer

INSERT A NODE: insertNode()

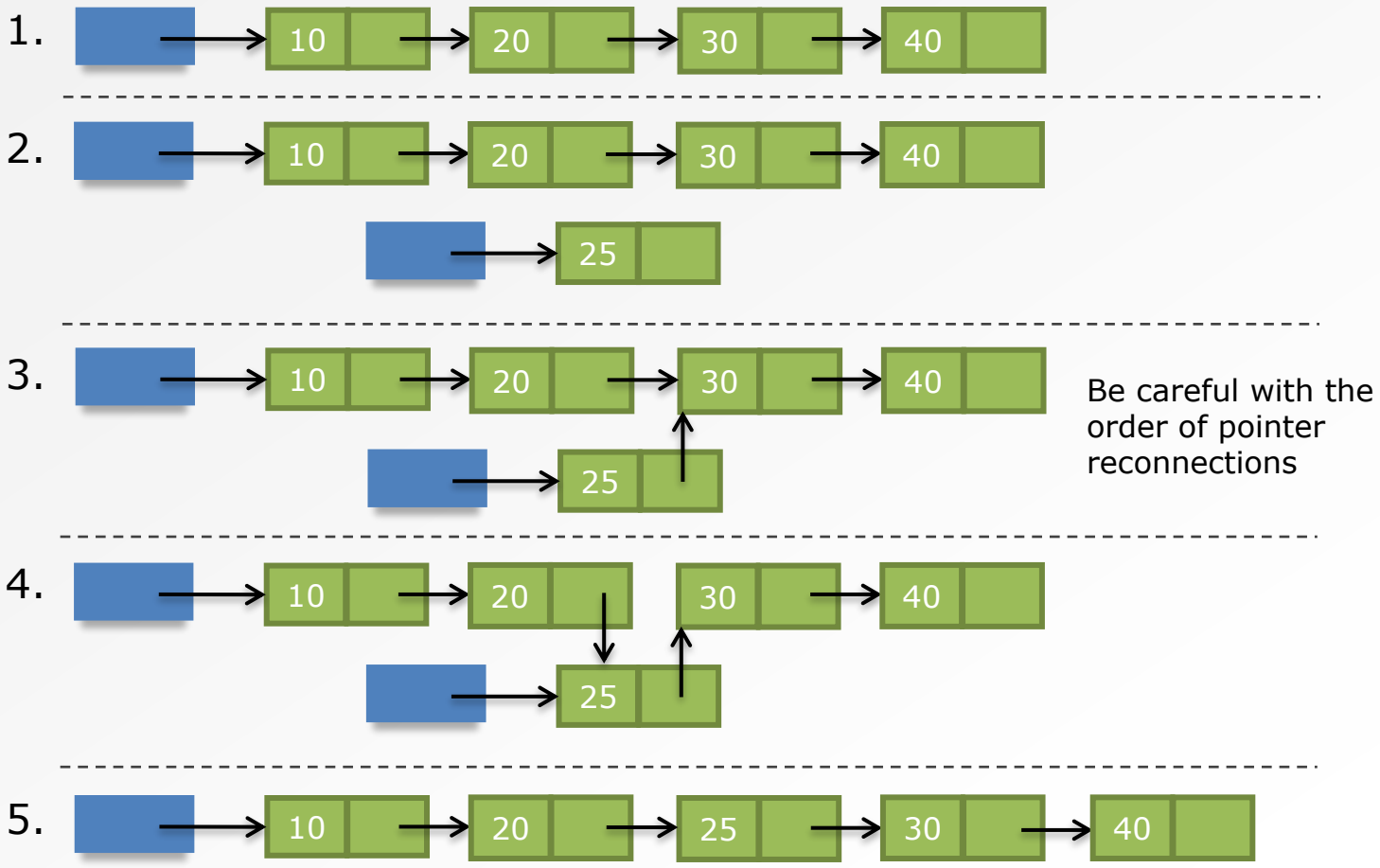
- Consider all the different places we want to add a node
  - Front
  - Back
  - Middle
- Consider all the different starting states of the linked list
  - Empty list
  - One node
  - Many nodes
- Ok to create many special cases and merge them later when we see similar code
- Get it right before you try to optimise
- Start with the case of adding a node in the middle of a linked list with many existing nodes
  - Several pointers to move around

INSERT A NODE: insertNode()

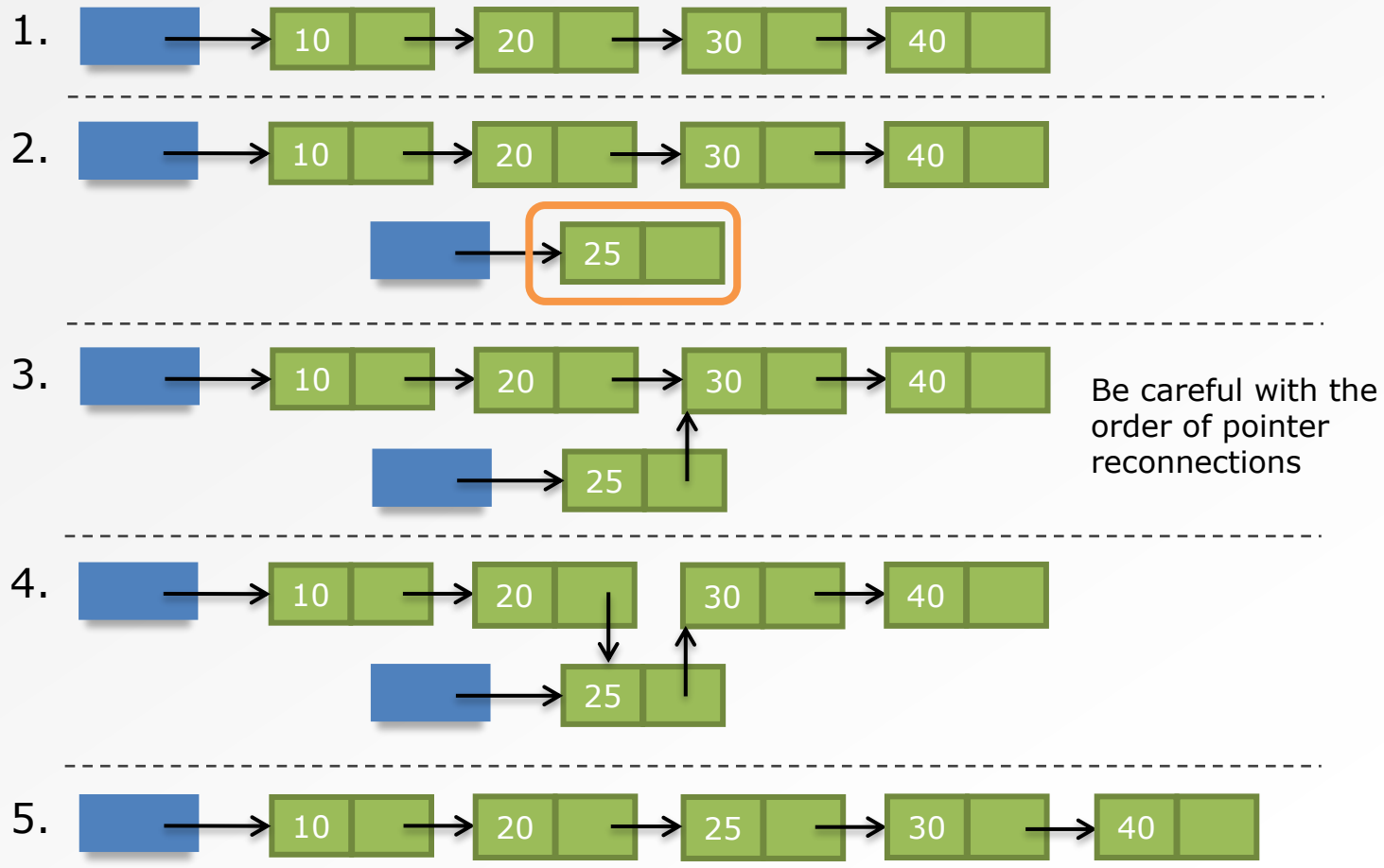
- Adding a node (25) in the middle of a linked list with many existing nodes



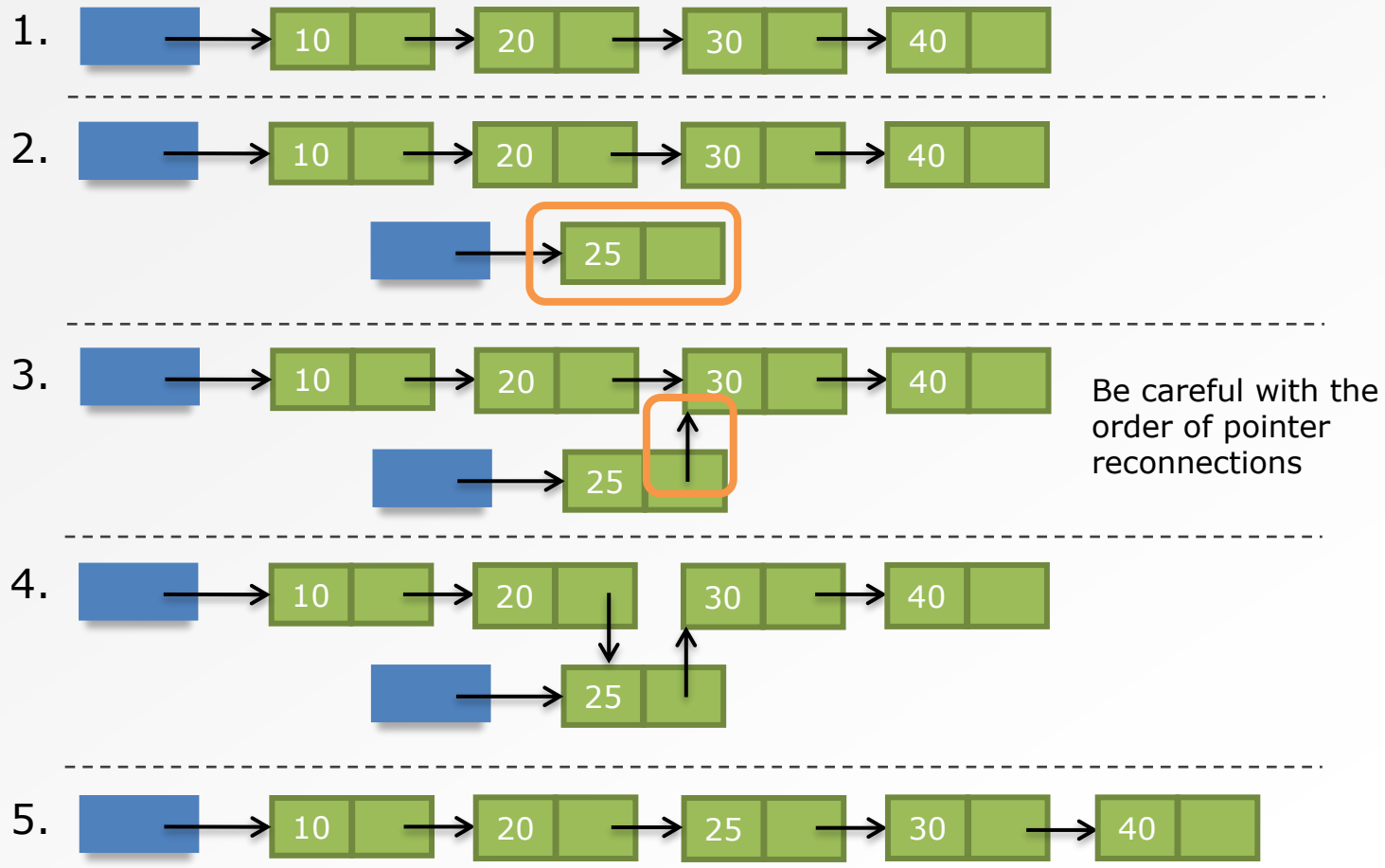
INSERT A NODE: insertNode()



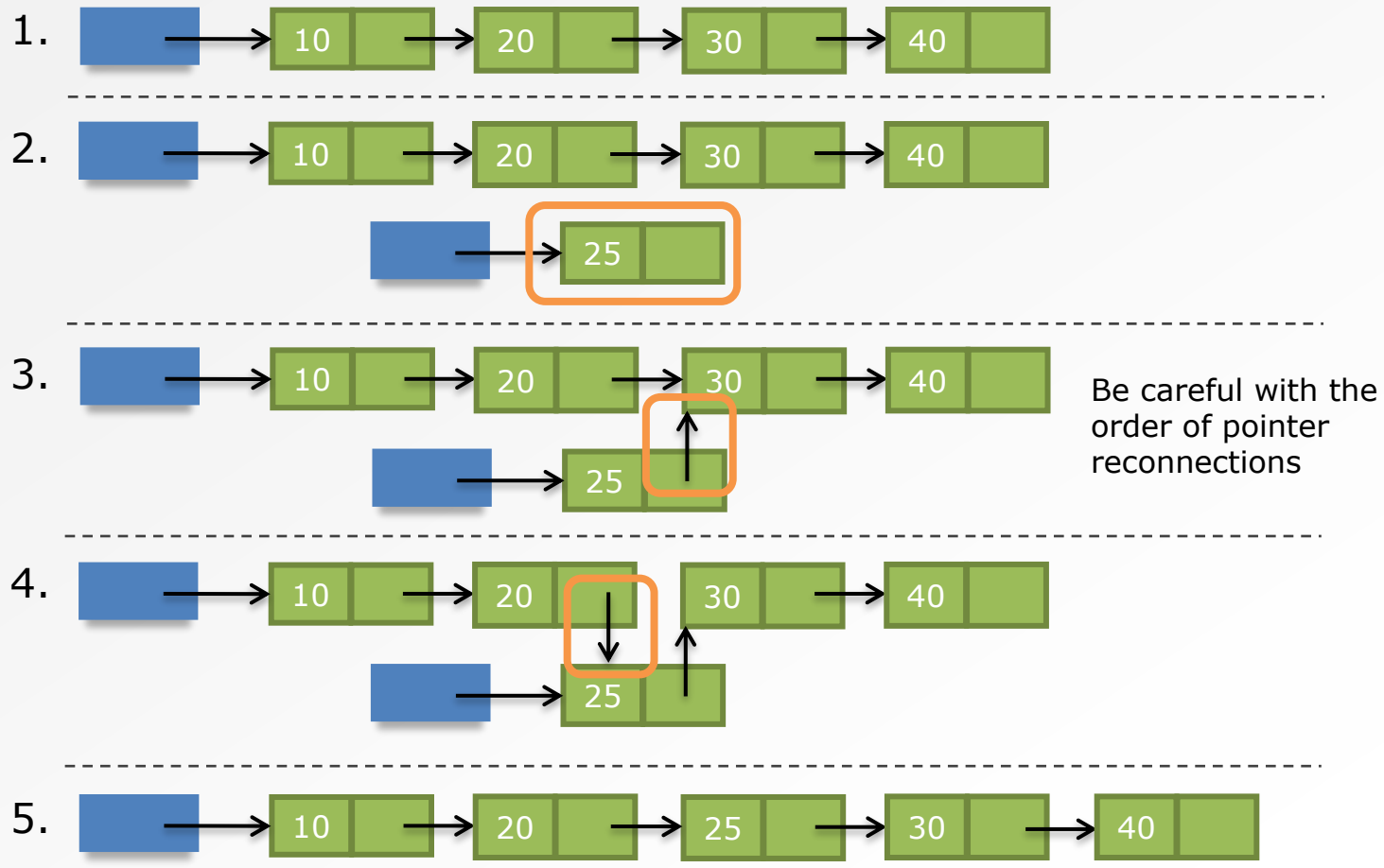
INSERT A NODE: insertNode()



INSERT A NODE: insertNode()



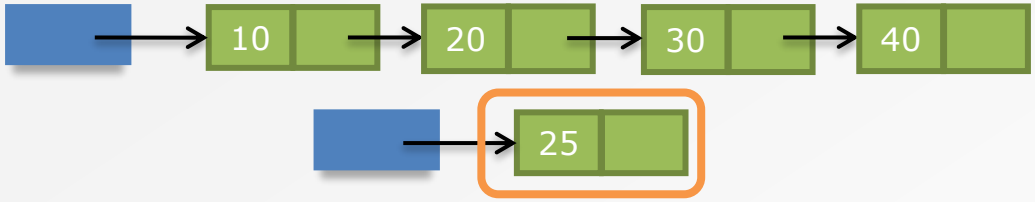
INSERT A NODE: insertNode()



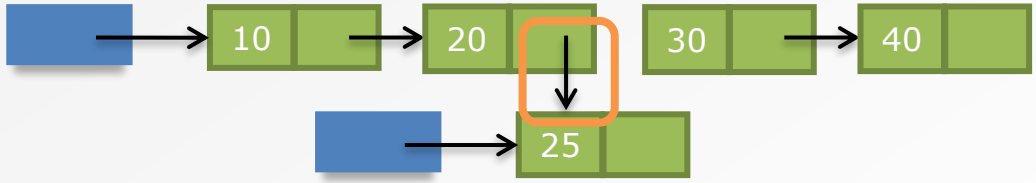
INSERT A NODE: insertNode()

- What if I first connect [20] to [25]?

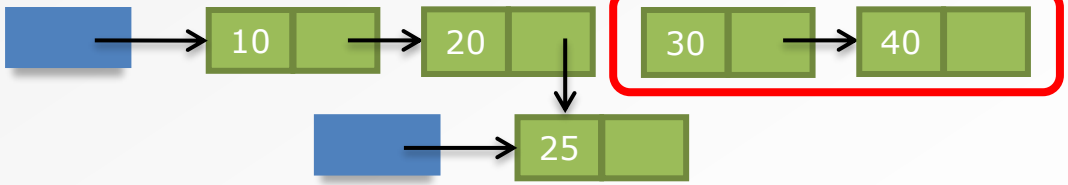
2.



3.

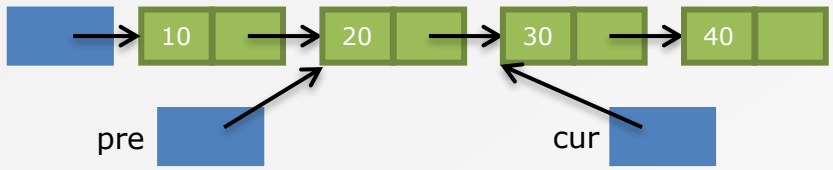


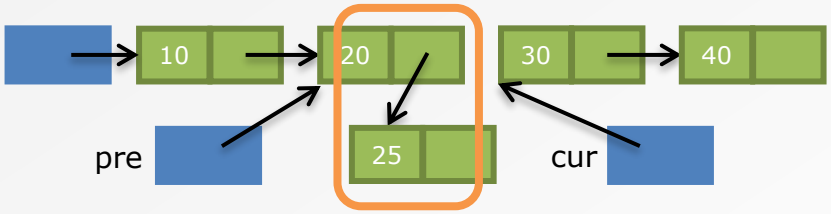
4.

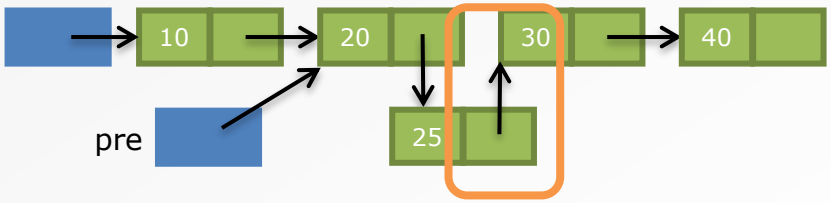


All gone! Inaccessible in memory since we lost the address of [30]

INSERT A NODE: insertNode()







Slightly different idea:
Use two pointers (pre, cur) to keep track of the nodes before and after where the new node will go

1. Set pre, cur
   Remember findNode()?

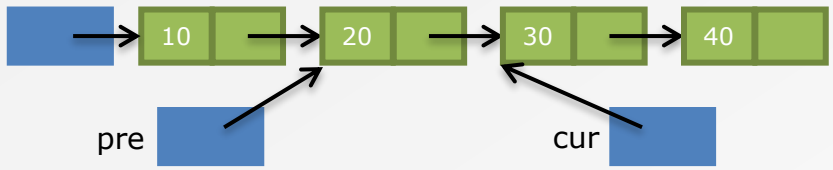
2. Create a new node and store its address in pre->next

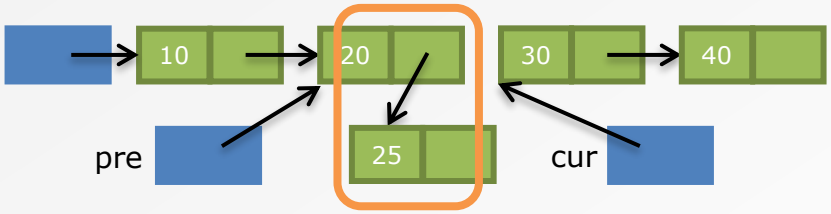
```
Pre->next = malloc(sizeof(ListNode));
```

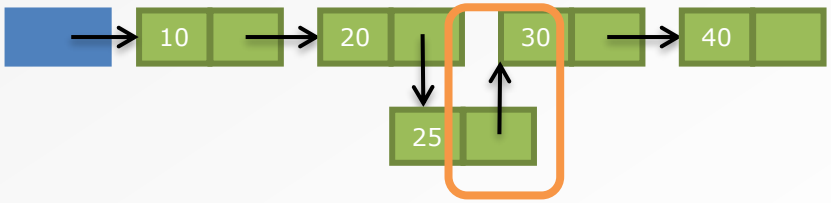
3. Set the new node's next pointer
   New node currently at pre->next
   Next pointer of new node is pre->next->next

```
Pre->next->next = cur
```

INSERT A NODE: insertNode()







Slightly different idea:
Use two pointers (pre, cur) to keep track of the nodes before and after where the new node will go

1. Set pre, cur
   Remember findNode()?

2. Create a new node and store its address in pre->next

   Pre->next = malloc(sizeof(ListNode));

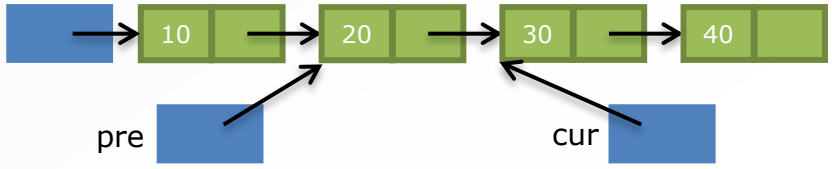
3. Set the new node's next pointer
   New node currently at pre->next
   Next pointer of new node is pre->next->next

   Pre->next->next = cur

insertNode() ["NORMAL CASE" PART]

- Use findNode() to get address of the pre pointer
- If inserting a new node at index 2, pre should point to node at index 1
  - findNode(… , index-1)

```
14    // Find the nodes before and at the target position
15       // Create a new node and reconnect the links
16       if ((pre = findNode(*ptrHead, index-1)) != NULL){
17           cur = pre->next;
18           pre->next = malloc(sizeof(ListNode));
19           pre->next->item = value;
20           pre->next->next = cur;
21           return 0;
22       }
23
24       return -1;
25   }
```



INSERT A NODE: insertNode()

- Now deal with special cases
  - Empty list

  - Inserting a node at index 0

- What is common to both special cases?

INSERT A NODE: insertNode()

- 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 = [addr of first node]
```

INSERT A NODE: insertNode()

- Answer:
  - The address stored in the head pointer must be changed
- Back to the actual insertNode() code
- Earlier question:
  - What is the parameter list?
- Does this work?

```
int insertNode(ListNode *head,  …  )
```

- Hint:
  - Can you change the address stored in the actual head pointer from inside the insertNode() function?

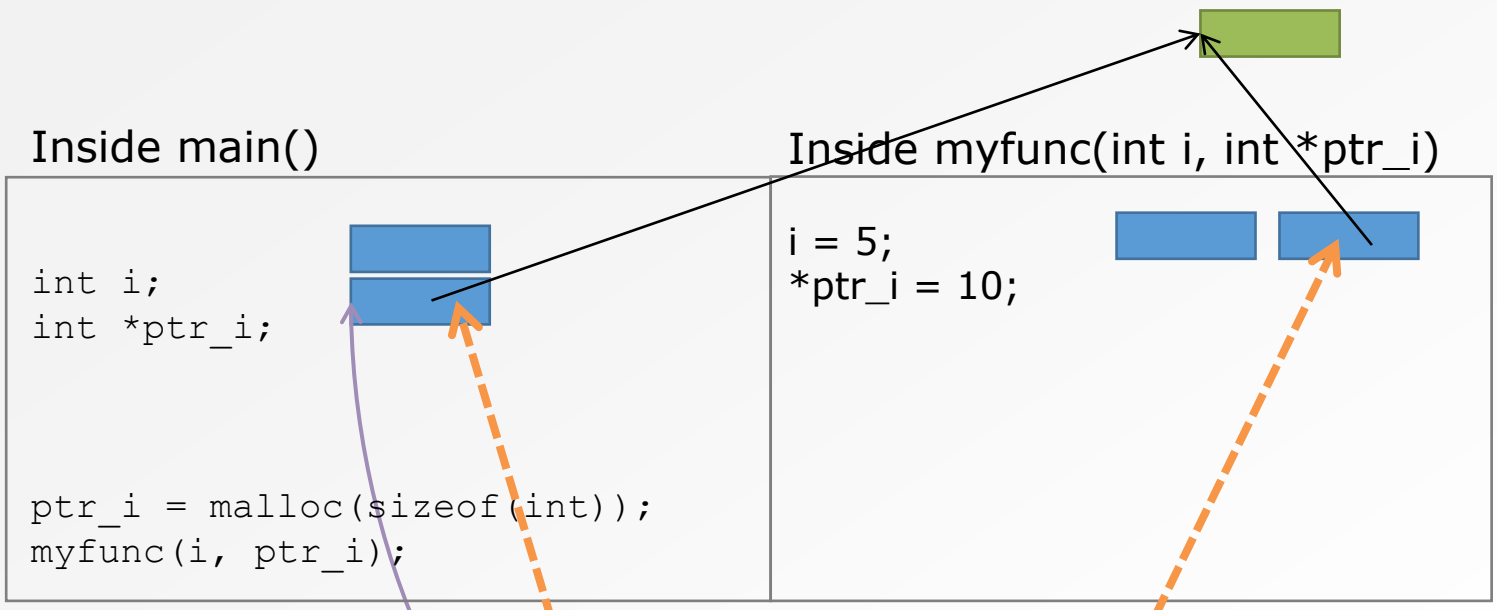
INSERT A NODE: insertNode()

- This does not work!

```
int insertNode(ListNode *head,  …  )
```

- If you are inserting a node into an empty list OR inserting a node at index 0 into an existing list
  - You need to change the address stored in the head pointer
- But you can only change the local copy of head pointer inside the insertNode() function
- Actual head pointer outside insertNode() remains unchanged!
- What is the solution when we want to modify a variable from inside a function?

REVISION: POINTERS AND PARAMETER PASSING



Pass in a pointer: You can change the value at the address store
BUT you cannot change the address stored in the pointer

To change the address you must pass in the ADDRESS of the pointer

This is also why we can use the local head pointer as a temporary pointer without destroying the head pointer back in the main() function

INSERT A NODE: insertNode()

- Pass in a pointer!
- Pointer to the variable we want to change
- The variable to be changed is the head pointer

```
ListNode *head
```

- We need to pass in a pointer to the head pointer

```
ListNode **head
```

- To make things clearer, we will rename this as

```
ListNode **ptrHead
```

  - Just to remind us that this is a pointer to the head pointer

INSERT A NODE: insertNode()

- Pass in a pointer!
- Pointer to the variable we want to change
- The variable to be changed is the head pointer

```
ListNode *head
```

- We need to pass in a pointer to the head pointer

```
ListNode **head
```

- To make things clearer, we will rename this as

```
ListNode **ptrHead
```

  - Just to remind us that this is a pointer to the head pointer
- **This lets us change the address that the head pointer points to**

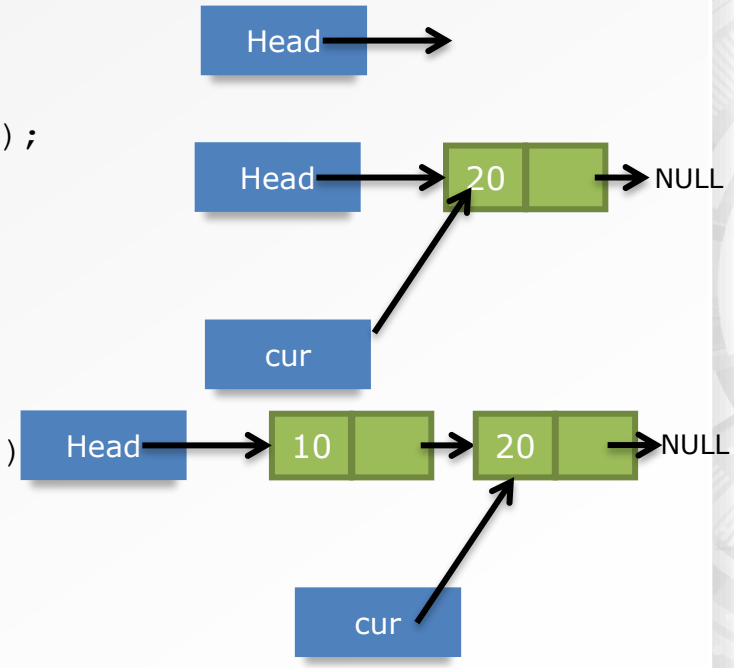
INSERT A NODE: insertNode()

- Can we combine any special cases?
  - Empty list

```
head = malloc(sizeof(ListNode));
head->next = null;
```

  - Inserting a node at index 0

```
cur = head;
head = malloc(sizeof(ListNode));
head->next = cur;
```



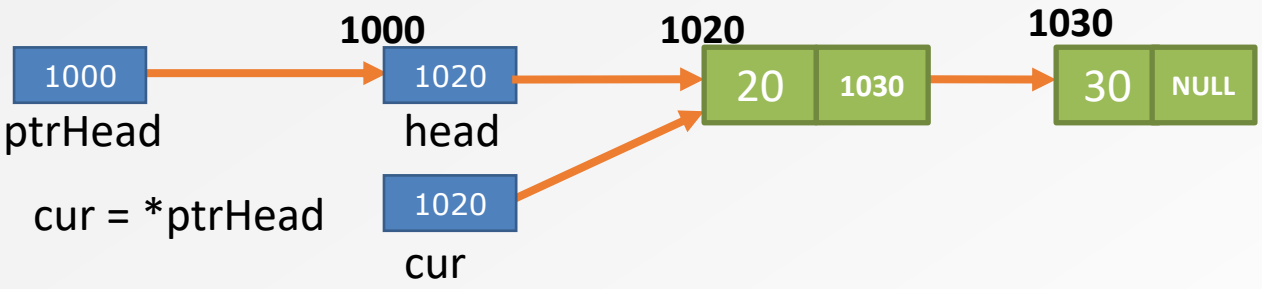
- Yes! In an empty list, head = NULL

insertNode()

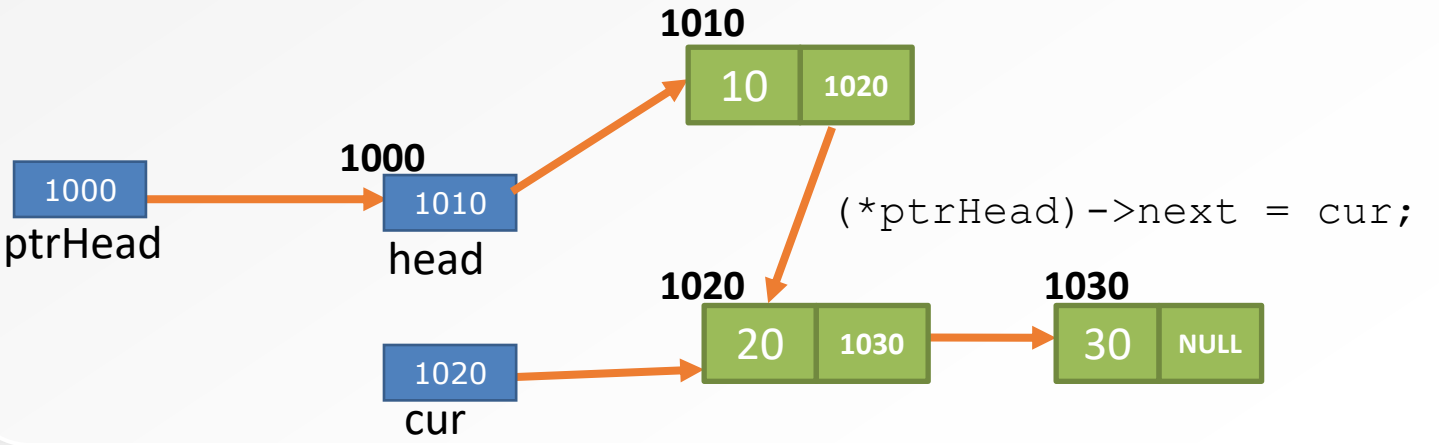
```
1    int insertNode(ListNode **ptrHead, int index, int value){
2
3        ListNode *pre, *cur;
4
5        // If empty list or inserting first node, need to update head pointer
6        if (*ptrHead == NULL || index == 0){
7            cur = *ptrHead;
8            *ptrHead = malloc(sizeof(ListNode));
9            (*ptrHead)->item = value;
10           (*ptrHead)->next = cur;
11           return 0;
12       }
13
14             // Find the nodes before and at the target position
15       // Create a new node and reconnect the links
16       if ((pre = findNode(*ptrHead, index-1)) != NULL){
17           cur = pre->next;
18           pre->next = malloc(sizeof(ListNode));
19           pre->next->item = value;
20           pre->next->next = cur;
21           return 0;
22       }
23
24       return -1;
25   }
```

INSERTING A NODE AT THE FRONT

```
int insertNode(ListNode **ptrHead, int index, int value)
```

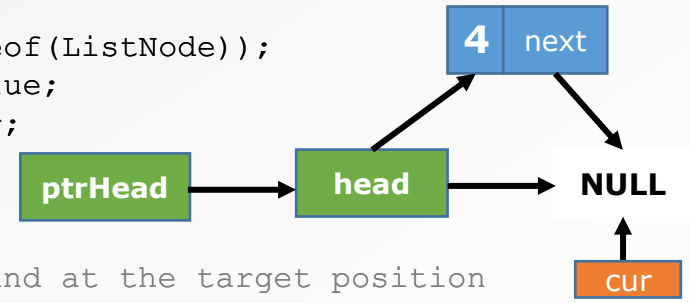



```
*ptrHead = malloc(sizeof(ListNode));
(*ptrHead)->item = 10;
```



insertNode(&head, 0, 4) example

```
1    int insertNode(ListNode **ptrHead, int index, int value){
2
3        ListNode *pre, *cur;
4
5        // If empty list or inserting first node, need to update head pointer
6        if (*ptrHead == NULL || index == 0){
7            cur = *ptrHead;
8            *ptrHead = malloc(sizeof(ListNode));
9            (*ptrHead)->item = value;
10           (*ptrHead)->next = cur;
11           return 0;
12       }
13
14       // Find the nodes before and at the target position
15       // Create a new node and reconnect the links
16       if ((pre = findNode(*ptrHead, index-1)) != NULL){
17           cur = pre->next;
18           pre->next = malloc(sizeof(ListNode));
19           pre->next->item = value;
20           pre->next->next = cur;
21           return 0;
22       }
23
24       return -1;
25   }
```



insertNode(&head, 1, 3) example

```
1    int insertNode(ListNode **ptrHead, int index, int value){
2
3        ListNode *pre, *cur;
4
5        // If empty list or inserting first node, need to update head pointer
6        if (*ptrHead == NULL || index == 0){
7            cur = *ptrHead;
8            *ptrHead = malloc(sizeof(ListNode));
9            (*ptrHead)->item = value;
10           (*ptrHead)->next = cur;
11           return 0;
12       }
13
14       // Find the nodes before and at the target position
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16       if ((pre = findNode(*ptrHead, index-1)) != NULL){
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23
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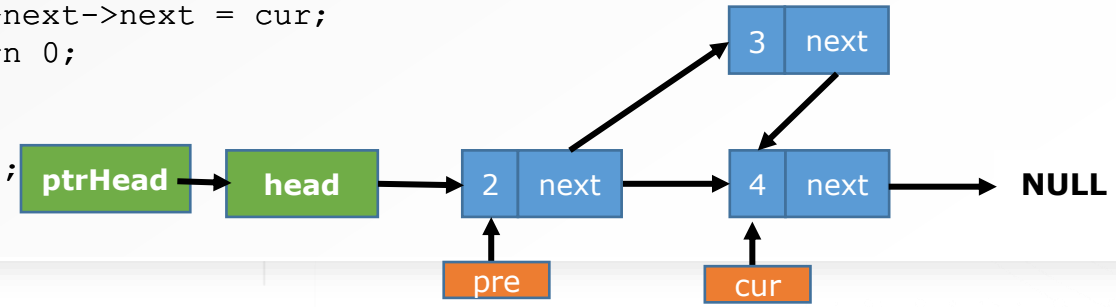
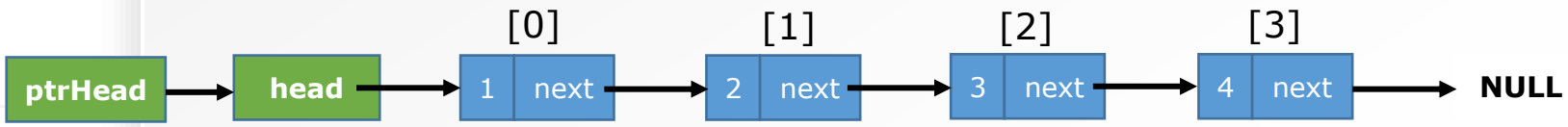
```



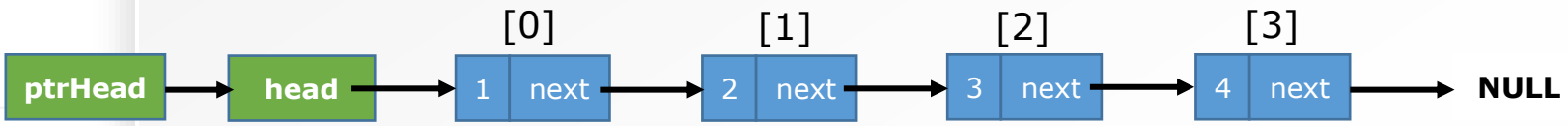
insertNode() example – insert node at front

```
1    int main(){
2        ListNode *head=NULL;
3        int size =0;
4
5        //creating the linked list - 0 2 1 4 3 6
6        insertNode(&head, 0, 4); size++;
7        insertNode(&head, 0, 3); size++;
8        insertNode(&head, 0, 2); size++;
9        insertNode(&head, 0, 1); size++;
10
11       return 0;
12   }
13
```



insertNode() example – insert node at index 0 and 1

```
1    int main(){
2        ListNode *head=NULL;
3        int size =0;
4
5        //creating the linked list - 0 2 1 4 3 6
6        insertNode(&head, 0, 4); size++;
7        insertNode(&head, 0, 2); size++;
8        insertNode(&head, 1, 3); size++;
9        insertNode(&head, 0, 1); size++;
10
11       return 0;
12   }
13
```



TODAY

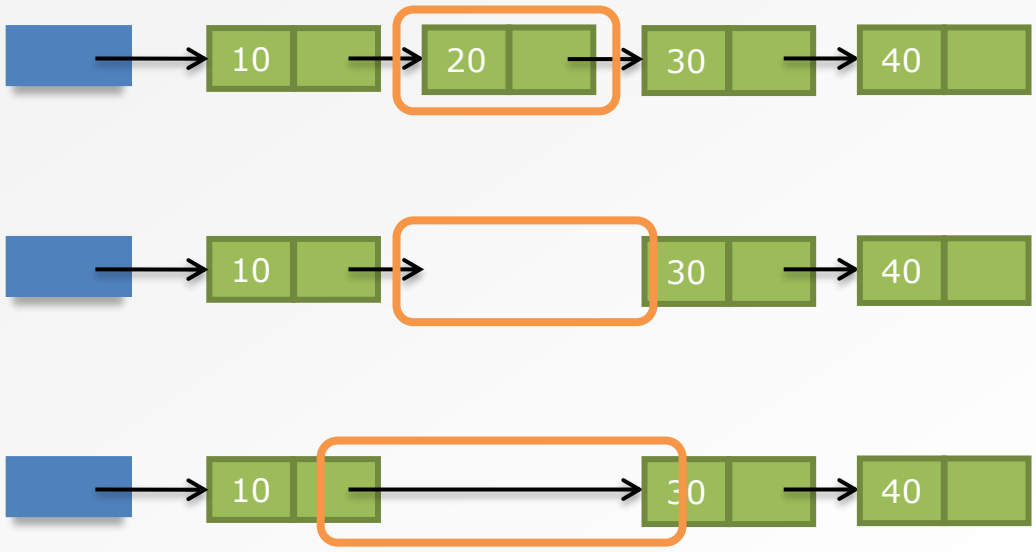
- ListNode structures
- Core linked list data structure functions
  - printList();
  - findNode();
  - insertNode()
  - **removeNode()**
- Common mistakes

REMOVE A NODE FROM ANY POSITION OF THE LINKED LIST: removeNode()

- Do this as one of your lab questions
- We will go through the basic diagrams
- You write the code
- Again, we need to pass in a pointer to the head pointer
  - In case we delete the first node, we have to change the address stored in the head pointer (outside, not the local copy)
  - What are the other special cases?

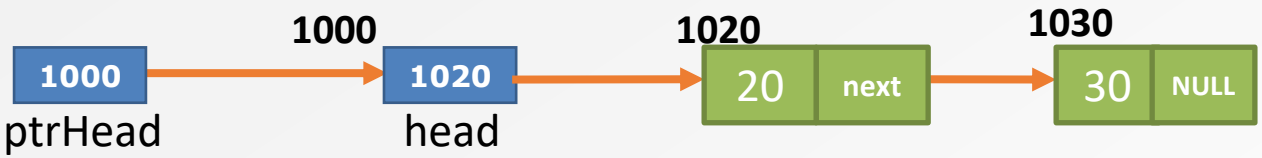
REMOVE A NODE: removeNode()

- Remember to free up any unused memory



REMOVING A NODE AT THE FRONT

```
int removeNode(ListNode **ptrHead, int index);
```



REMOVING A NODE AT THE FRONT

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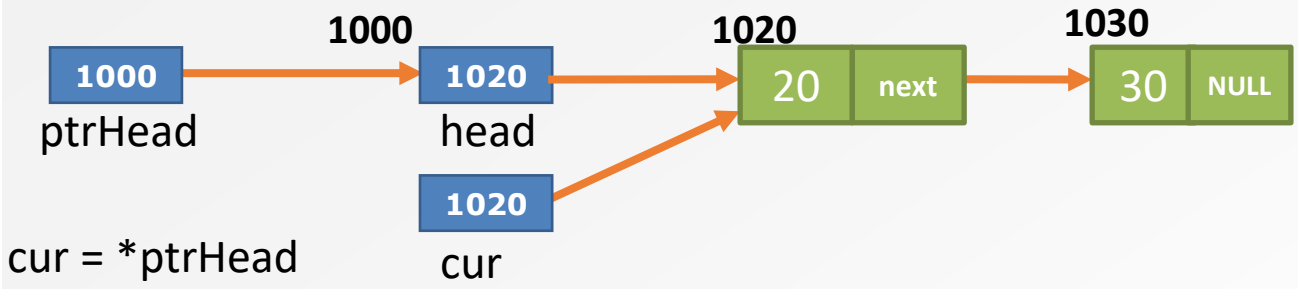
int removeNode(ListNode **ptrHead, int index);
```



REMOVING A NODE AT THE FRONT

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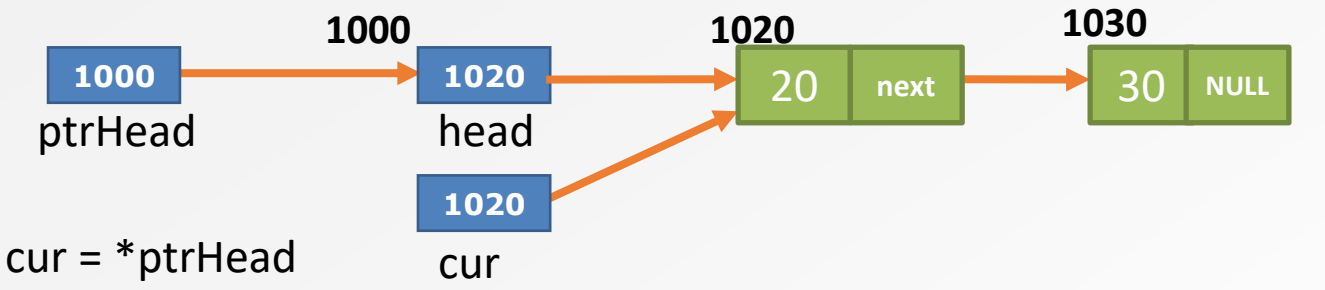
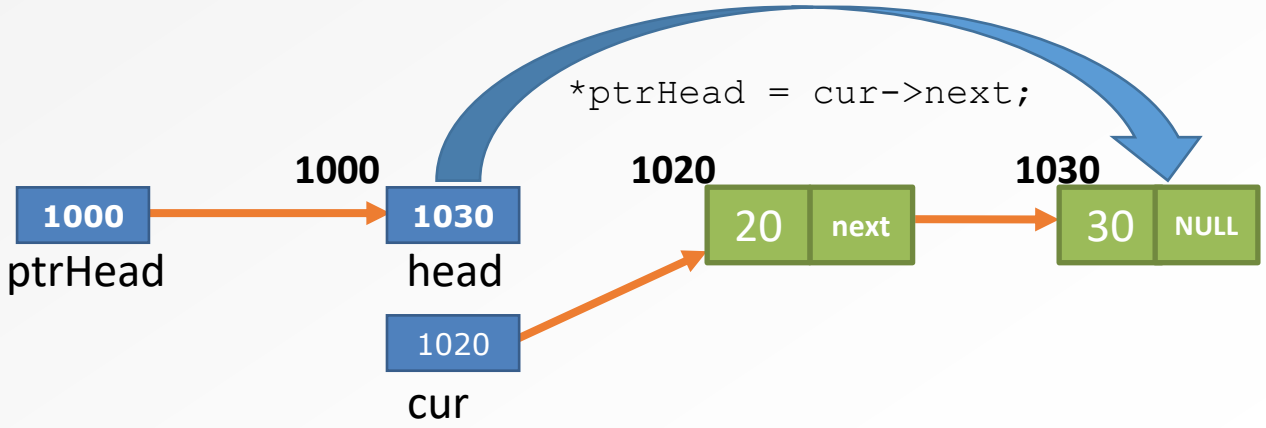
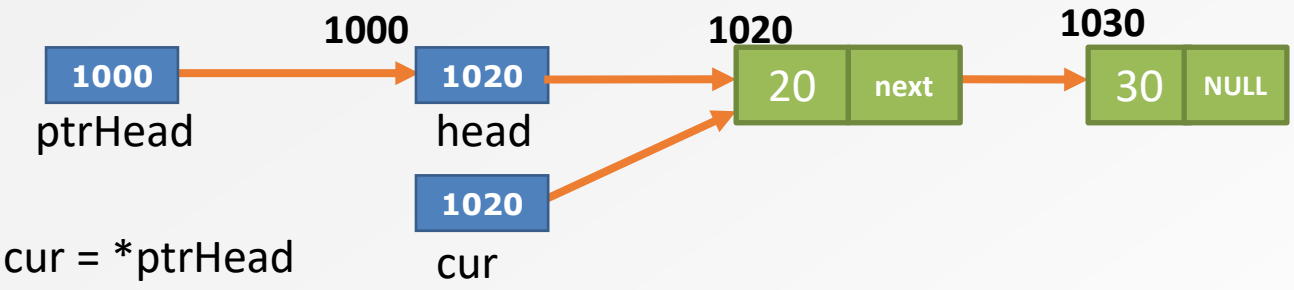
int removeNode(ListNode **ptrHead, int index);
```

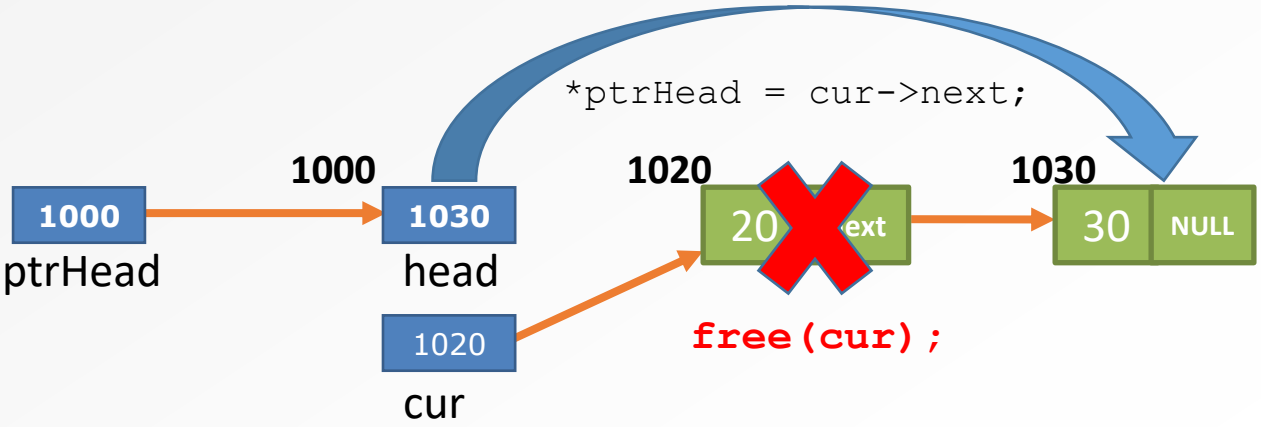




REMOVING A NODE AT THE FRONT

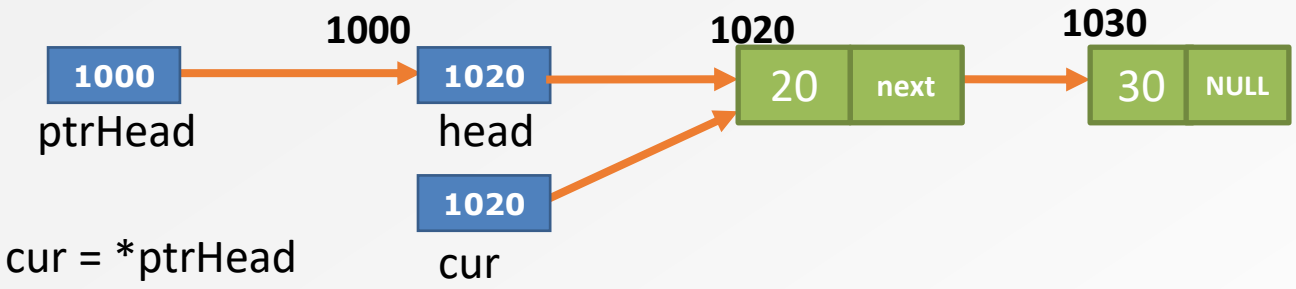
```
int removeNode(ListNode **ptrHead, int index);
```

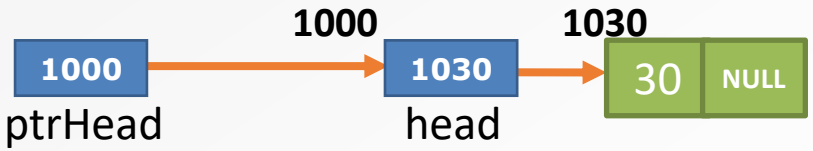




REMOVING A NODE AT THE FRONT

```
int removeNode(ListNode **ptrHead, int index);
```





TODAY

- ListNode structures
- Core linked list data structure functions
  - printList();
  - findNode();
  - insertNode()
  - removeNode()
- **Common mistakes**

COMMON MISTAKES

- What is cur?
- What is pre?
- State three ways of getting the address of the node at index 2 (third node)