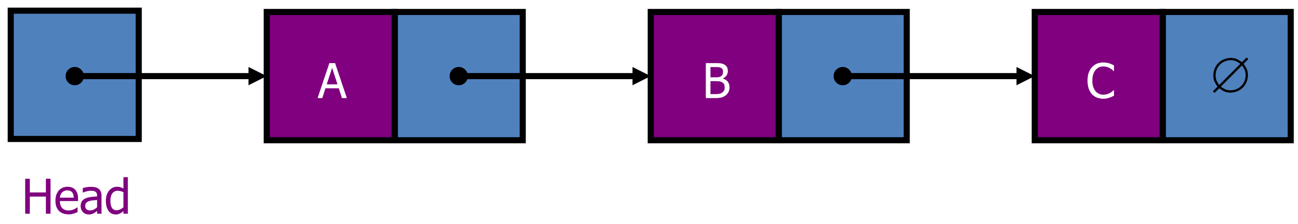
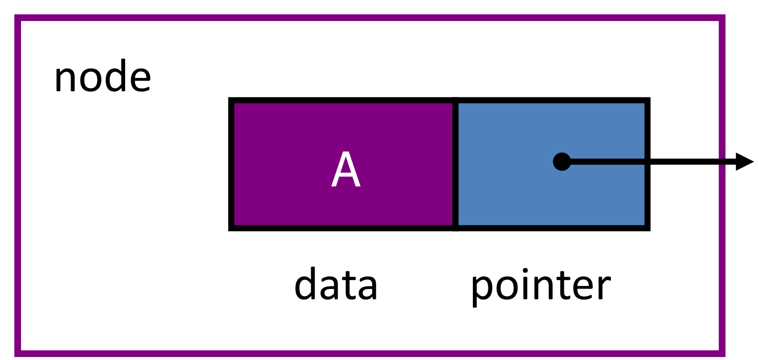
CS 2133
Linked Lists

Linked Lists



- A *linked list* is a series of connected *nodes*
- Each node contains at least
  - A piece of data (any type)
  - Pointer to the next node in the list
- *Head*: pointer to the first node
- The last node points to `NULL`



A Simple Linked List Class

- We use two classes: **`Node`** and **`List`**
- Declare `Node` class for the nodes
  - `data`: `double`-type data in this example
  - `next`: a pointer to the next node in the list

```
class Node {
public:
        double data;            // data
        Node*       next;           // pointer to next
};
```

A Simple Linked List Class

- Declare `List`, which contains
  - `head`: a pointer to the first node in the list.
    Since the list is empty initially, `head` is set to `NULL`
  - Operations on `List`

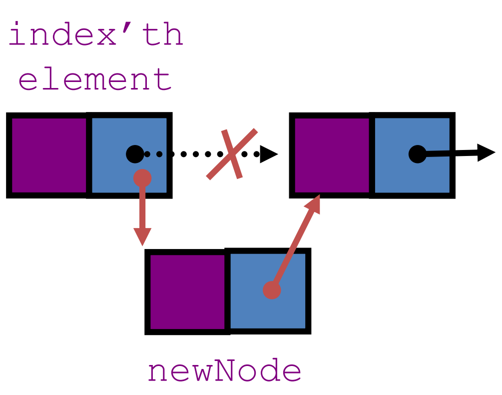
```
class List {
public:
      List(void) { head = NULL; }        // constructor
      ~List(void);                       // destructor

      bool IsEmpty() { return head == NULL; }
      Node* InsertNode(int index, double x);
      int FindNode(double x);
      int DeleteNode(double x);
      void DisplayList(void);
private:
      Node* head;
};
```

A Simple Linked List Class

- Operations of `List`
  - `IsEmpty`: determine whether or not the list is empty
  - `InsertNode`: insert a new node at a particular position
  - `FindNode`: find a node with a given value
  - `DeleteNode`: delete a node with a given value
  - `DisplayList`: print all the nodes in the list

Inserting a new node

- `Node* InsertNode(int index, double x)`
  - Insert a node with data equal to `x` after the `index'th` elements. (i.e., when `index = 0`, insert the node as the first element; when `index = 1`, insert the node after the first element, and so on)
  - If the insertion is successful, return the inserted node. Otherwise, return `NULL`. (If `index` is < 0 or > length of the list, the insertion will fail.)
- Steps
  1. Locate `index`'th element
  2. Allocate memory for the new node
  3. Point the new node to its successor
  4. Point the new node's predecessor to the new node



Inserting a new node

- Possible cases of `InsertNode`
  1. Insert into an empty list
  2. Insert in front
  3. Insert at back
  4. Insert in middle
- But, in fact, only need to handle two cases
  - Insert as the first node (Case 1 and Case 2)
  - Insert in the middle or at the end of the list (Case 3 and Case 4)

Inserting a new node

```
Node* List::InsertNode(int index, double x) {
    if (index < 0) return NULL;

    int currIndex  =      1;
    Node* currNode =      head;
    while (currNode && index > currIndex) {
           currNode       =      currNode->next;
           currIndex++;
    }
    if (index > 0 && currNode == NULL) return NULL;

    Node* newNode  =      new    Node;
    newNode->data  =      x;
    if (index == 0) {
           newNode->next  =      head;
           head           =      newNode;
    }
    else {
           newNode->next  =      currNode->next;
           currNode->next =      newNode;
    }
    return newNode;
}
```

Try to locate `index`'th node. If it doesn't exist, return `NULL`.

Inserting a new node

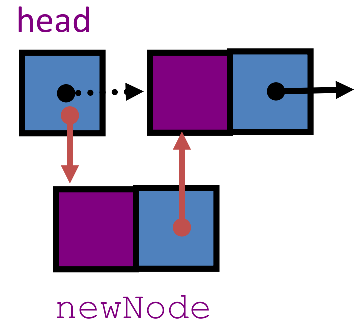
```
Node* List::InsertNode(int index, double x) {
       if (index < 0) return NULL;

       int currIndex  =       1;
       Node* currNode =       head;
       while (currNode && index > currIndex) {
              currNode        =       currNode->next;
              currIndex++;
       }
       if (index > 0 && currNode == NULL) return NULL;

       Node* newNode  =       new     Node;
       newNode->data  =       x;
       if (index == 0) {
              newNode->next   =       head;
              head            =       newNode;
       }
       else {
              newNode->next   =       currNode->next;
              currNode->next =        newNode;
       }
       return newNode;
}
```

Create a new node

Inserting a new node

```
Node* List::InsertNode(int index, double x) {
        if (index < 0) return NULL;

        int currIndex  =        1;
        Node* currNode =        head;
        while (currNode && index > currIndex) {
                currNode        =       currNode->next;
                currIndex++;
        }
        if (index > 0 && currNode == NULL) return NULL;

        Node* newNode  =        new     Node;
        newNode->data  =        x;
        if (index == 0) {
                newNode->next   =       head;
                head            =       newNode;
        }
        else {
                newNode->next   =       currNode->next;
                currNode->next =        newNode;
        }
        return newNode;
}
```

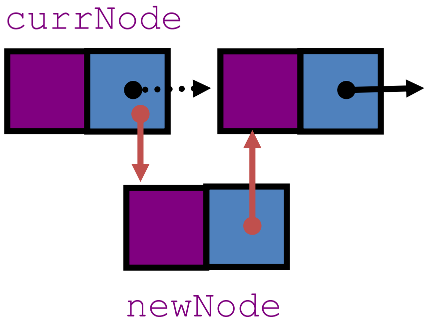
Insert as first element



Inserting a new node

```
Node* List::InsertNode(int index, double x) {
       if (index < 0) return NULL;

       int currIndex  =       1;
       Node* currNode =       head;
       while (currNode && index > currIndex) {
              currNode        =       currNode->next;
              currIndex++;
       }
       if (index > 0 && currNode == NULL) return NULL;

       Node* newNode  =       new     Node;
       newNode->data  =       x;
       if (index == 0) {
              newNode->next   =       head;
              head            =       newNode;
       }
       else {
              newNode->next   =       currNode->next;
              currNode->next  =       newNode;
       }
       return newNode;
}
```

Insert after `currNode`



Finding a node

- `int FindNode(double x)`
  - Search for a node with the value equal to `x` in the list.
  - If such a node is found, return its position. Otherwise, return 0.

```
int List::FindNode(double x) {
      Node* currNode      =      head;
      int currIndex =     1;
      while (currNode && currNode->data != x) {
            currNode      =      currNode->next;
            currIndex++;
      }
      if (currNode) return currIndex;
      return 0;
}
```

Deleting a node

- `int DeleteNode(double x)`
  - Delete a node with the value equal to `x` from the list.
  - If such a node is found, return its position. Otherwise, return 0.
- Steps
  - Find the desirable node (similar to `FindNode`)
  - Release the memory occupied by the found node
  - Set the pointer of the predecessor of the found node to the successor of the found node
- Like `InsertNode`, there are two special cases
  - Delete first node
  - Delete the node in middle or at the end of the list

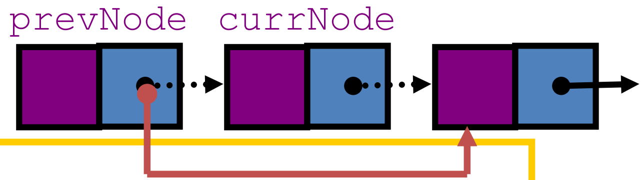
Deleting a node

```
int List::DeleteNode(double x) {
        Node* prevNode =        NULL;
        Node* currNode =        head;
        int currIndex  =        1;
        while (currNode && currNode->data != x) {
                prevNode        =       currNode;
                currNode        =       currNode->next;
                currIndex++;
        }
        if (currNode) {
                if (prevNode) {
                        prevNode->next =       currNode->next;
                        delete currNode;
                }
                else {
                        head            =       currNode->next;
                        delete currNode;
                }
                return currIndex;
        }
        return 0;
}
```

Try to find the node with its value equal to x

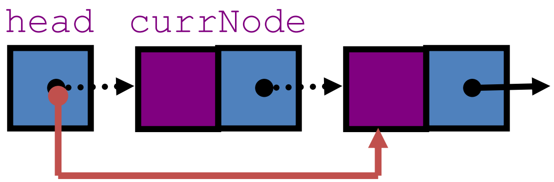
Deleting a node

```
int List::DeleteNode(double x) {
	Node* prevNode =	NULL;
	Node* currNode =	head;
	int currIndex  =	1;
	while (currNode && currNode->data != x) {
		prevNode	=	currNode;
		currNode	=	currNode->next;
		currIndex++;
	}
	if (currNode) {
		if (prevNode) {
			prevNode->next =	currNode->next;
			delete currNode;
		}
		else {
			head		=	currNode->next;
			delete currNode;
		}
		return currIndex;
	}
	return 0;
}
```



Deleting a node

```
int List::DeleteNode(double x) {
        Node* prevNode =        NULL;
        Node* currNode =        head;
        int currIndex  =        1;
        while (currNode && currNode->data != x) {
                prevNode        =       currNode;
                currNode        =       currNode->next;
                currIndex++;
        }
        if (currNode) {
                if (prevNode) {
                        prevNode->next =        currNode->next;
                        delete currNode;
                }
                else {
                        head            =       currNode->next;
                        delete currNode;
                }
                return currIndex;
        }
        return 0;
}
```



Printing all the elements

- `void DisplayList(void)`
  - Print the data of all the elements
  - Print the number of the nodes in the list

```
void List::DisplayList()
{
    int num             =      0;
    Node* currNode      =      head;
    while (currNode != NULL){
        cout << currNode->data << endl;
        currNode        =      currNode->next;
        num++;
    }
    cout << "Number of nodes in the list: " << num << endl;
}
```

Destroying the list

- `~List(void)`
  - Use the destructor to release all the memory used by the list.
  - Step through the list and delete each node one by one.

```
List::~List(void) {
   Node* currNode = head, *nextNode = NULL;
   while (currNode != NULL)
   {
       nextNode      =      currNode->next;
       // destroy the current node
       delete currNode;
       currNode      =      nextNode;
   }
}
```

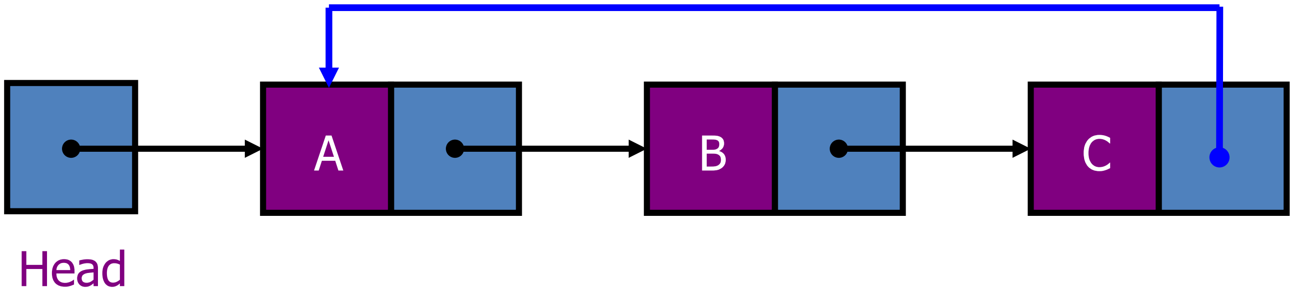
```
int main(void)
{
        List li
        list.In
        list.In
        list.In
        list.In
        list.In
        // prin
        list.Di
        if(list
        else                                            ndl;
        if(list.FindNode(4.5) > 0) cout << "4.5 found" << endl;
        else                         cout << "4.5 not found" << endl;
        list.DeleteNode(7.0);
        list.DisplayList();
        return 0;
}
```

result

6
7
5
Number of nodes in the list: 3
5.0 found
4.5 not found
6
5
Number of nodes in the list: 2

Variations of Linked Lists

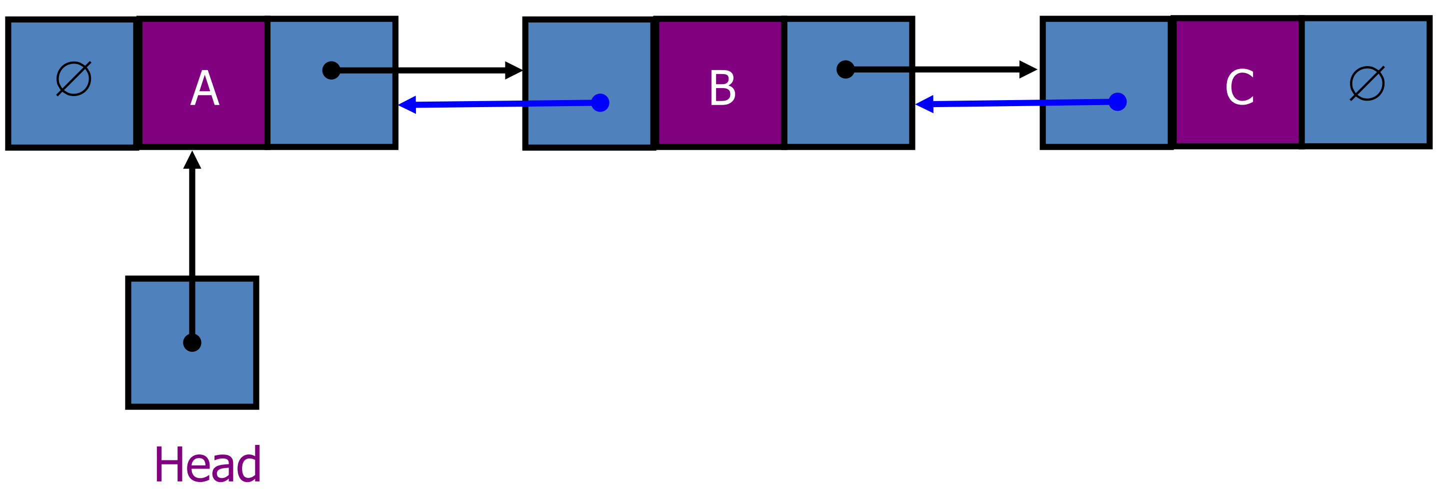
- *Circular linked lists*
  - The last node points to the first node of the list



  - How do we know when we have finished traversing the list? (Tip: check if the pointer of the current node is equal to the head.)

Variations of Linked Lists

- *Doubly linked lists*
  - Each node points to not only successor but the predecessor
  - There are two `NULL`: at the first and last nodes in the list
  - Advantage: given a node, it is easy to visit its predecessor. Convenient to traverse lists backwards



Array versus Linked Lists

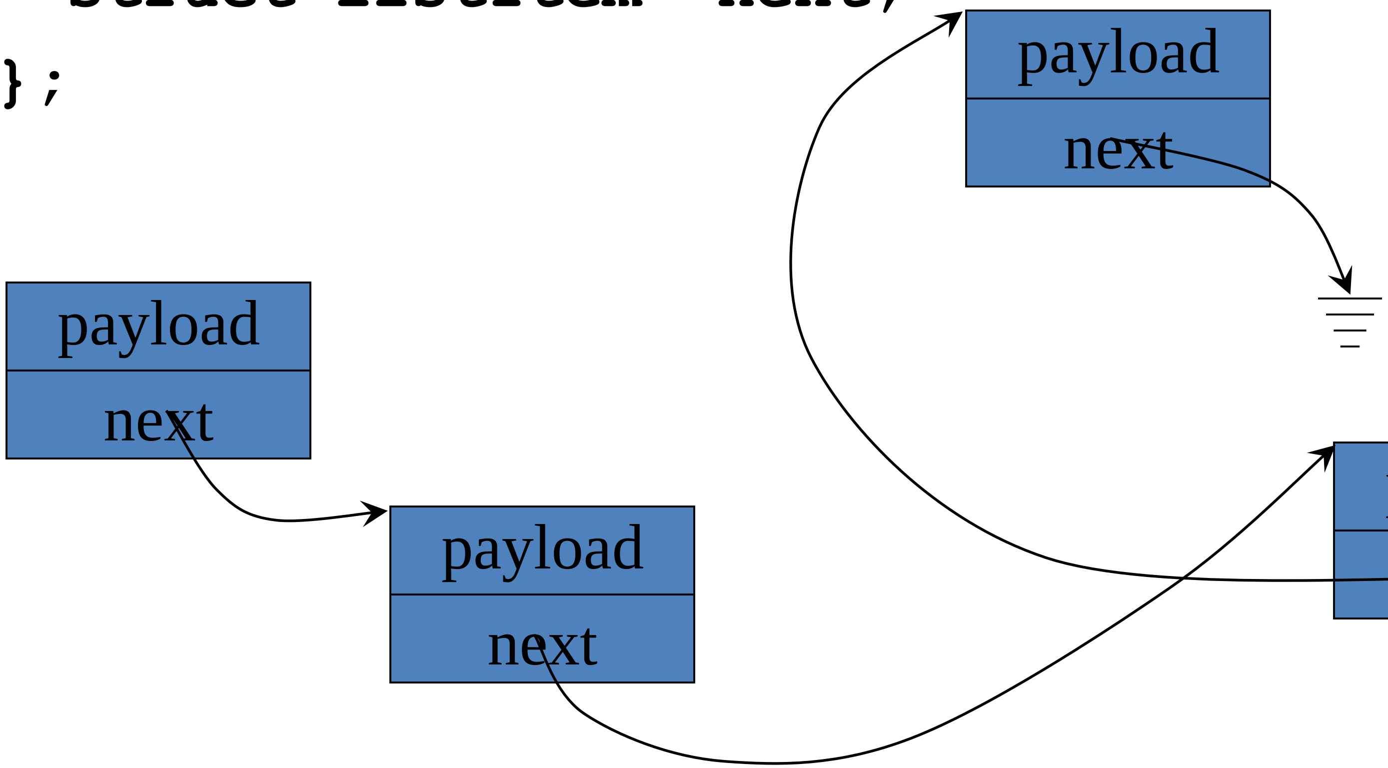
- Linked lists are more complex to code and manage than arrays, but they have some distinct advantages.
  - **Dynamic**: a linked list can easily grow and shrink in size.
    - We don't need to know how many nodes will be in the list. They are created in memory as needed.
    - In contrast, the size of a C++ array is fixed at compilation time.
  - **Easy and fast insertions and deletions**
    - To insert or delete an element in an array, we need to copy to temporary variables to make room for new elements or close the gap caused by deleted elements.
    - With a linked list, no need to move other nodes. Only need to reset some pointers.

One more example

- Here, *struct* is used instead of *class*.
- You are expected to re-implement this example using *class*

```
struct listItem {
  type payload;
  struct listItem *next;
};
```

Note: payload may be multiple members.



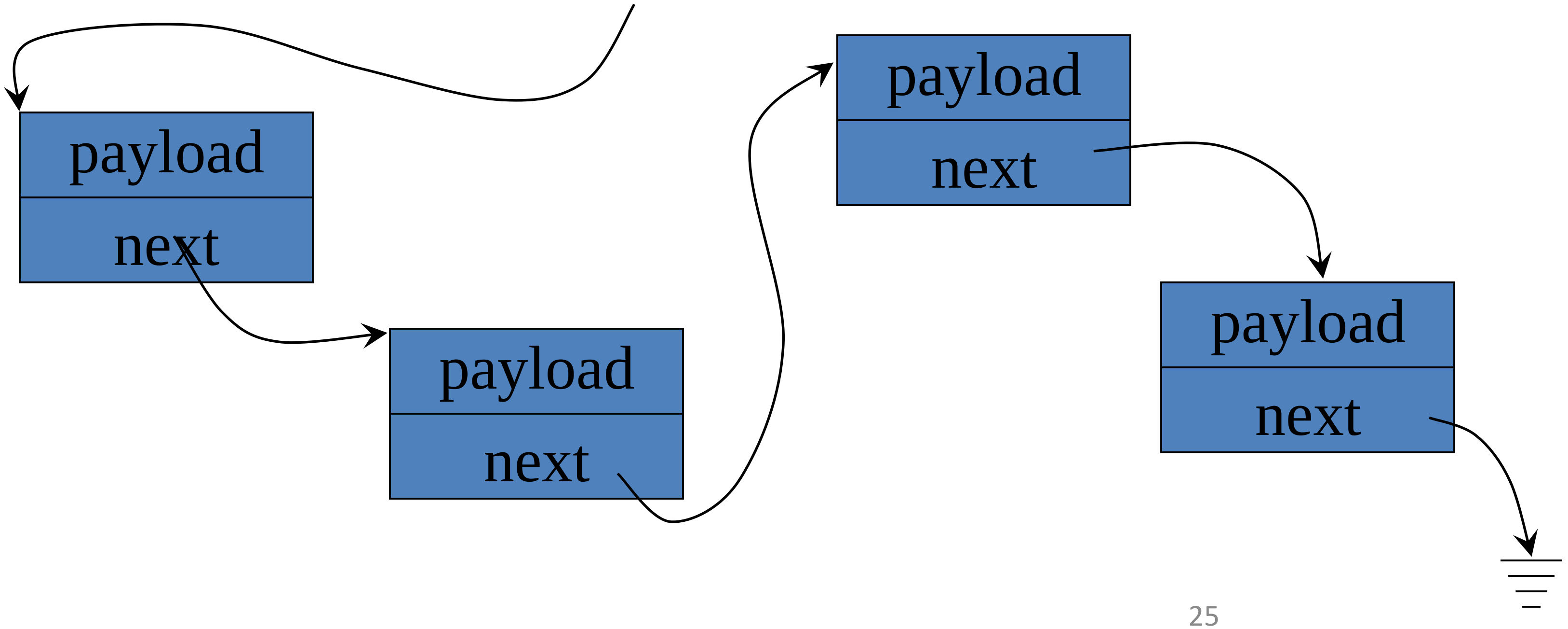
Linked List - Examples

- Items of list are usually same type
    - Generally obtained from **`malloc()`**
- Each item points to next item
- Last item points to null
- Need "**`head`**" to point to first item!

- "Payload" of item may be almost anything
    - A single member or multiple members
    - Any type of object whose size is known at compile time
    - Including **`struct`**, **`union`**, **`char *`** or other pointers
    - Also arrays of fixed size at compile time (see p. 214)

Linked List - Examples

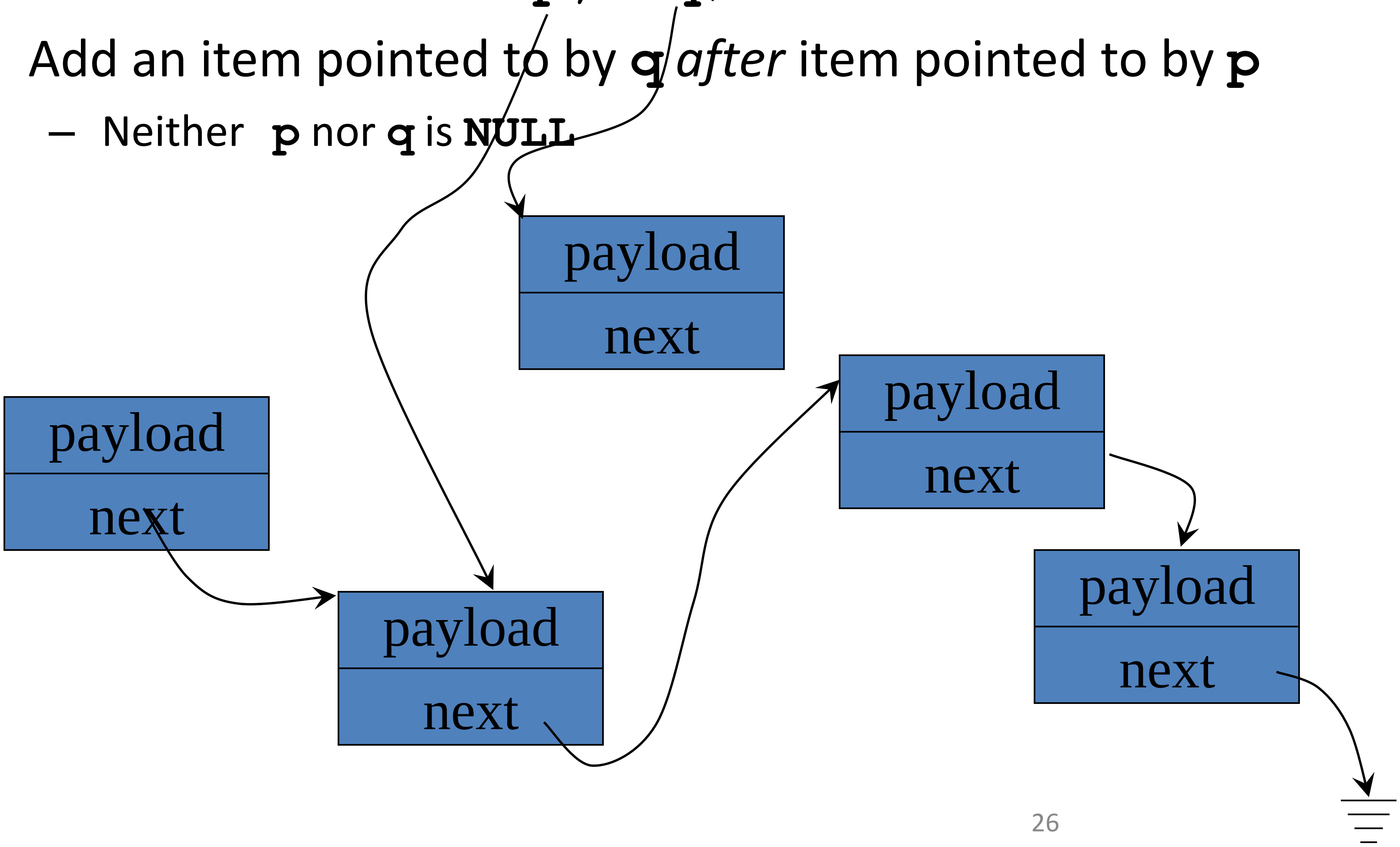
```
struct listItem {
   type payload;
   struct listItem *next;
};
struct listItem *head;
```



Adding an Item to a List

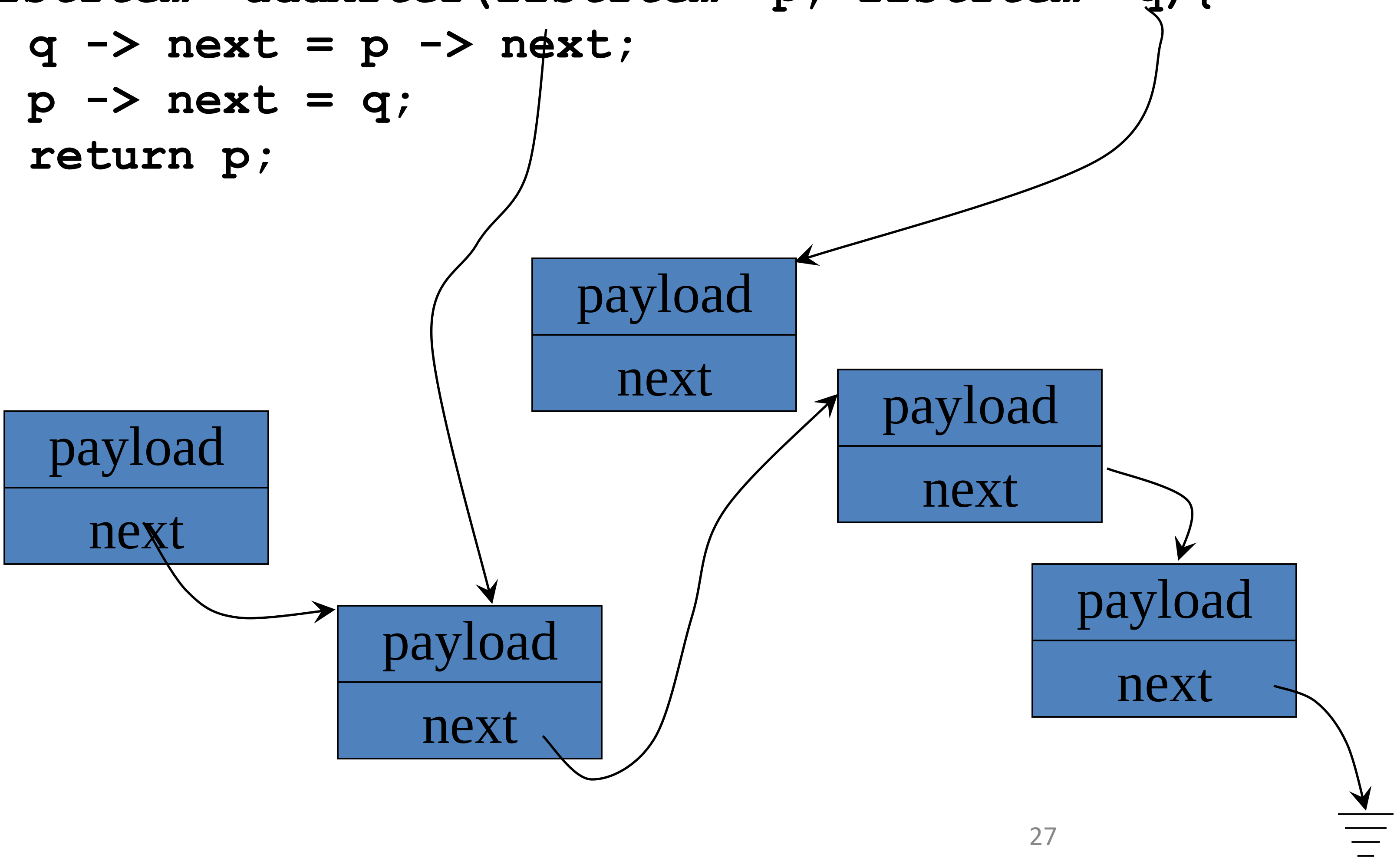
```
struct listItem *p, *q;
```

- Add an item pointed to by **q** *after* item pointed to by **p**
  - Neither **p** nor **q** is **NULL**



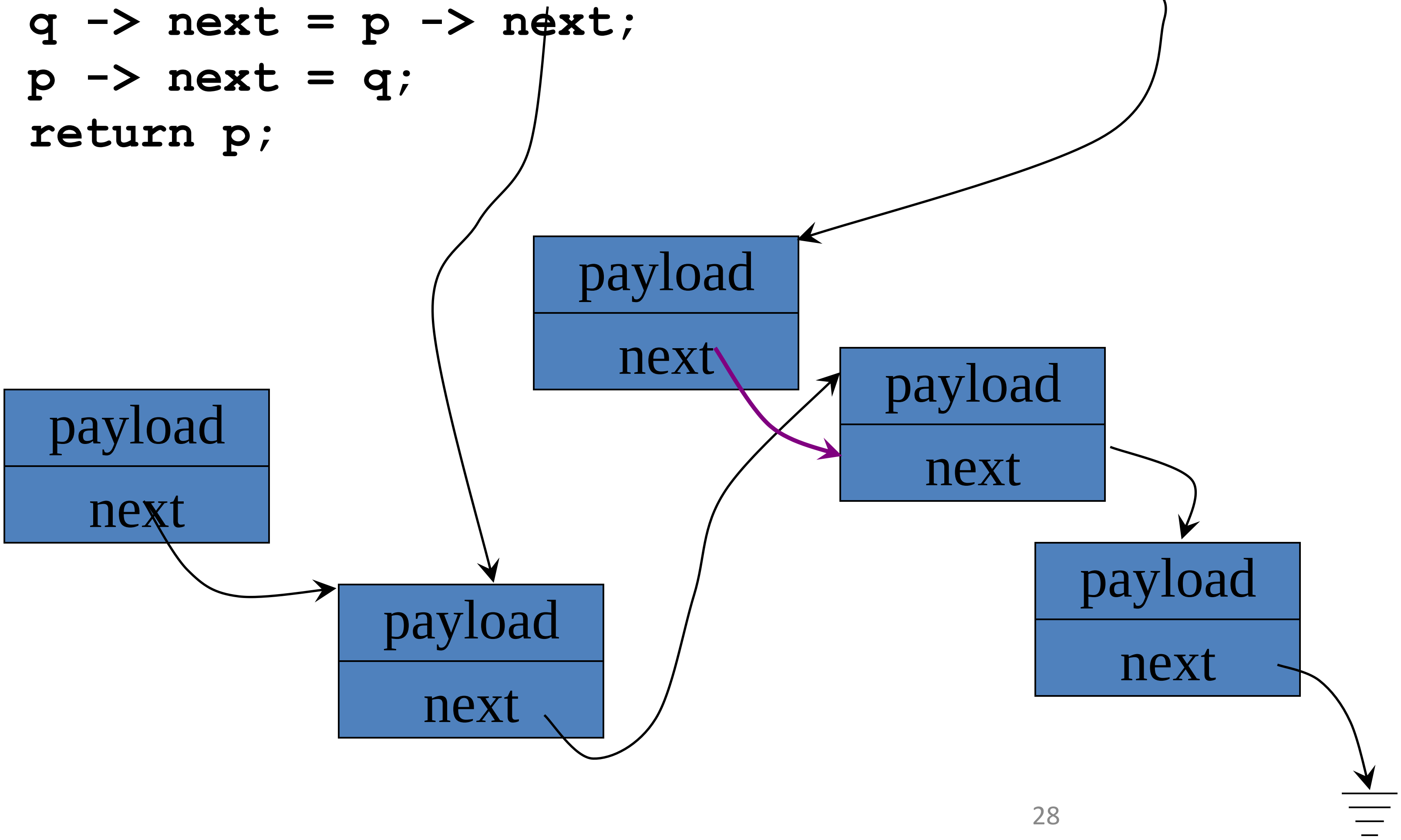
Adding an Item to a List

```
listItem *addAfter(listItem *p, listItem *q){
   q -> next = p -> next;
   p -> next = q;
   return p;
}
```



Adding an Item to a List

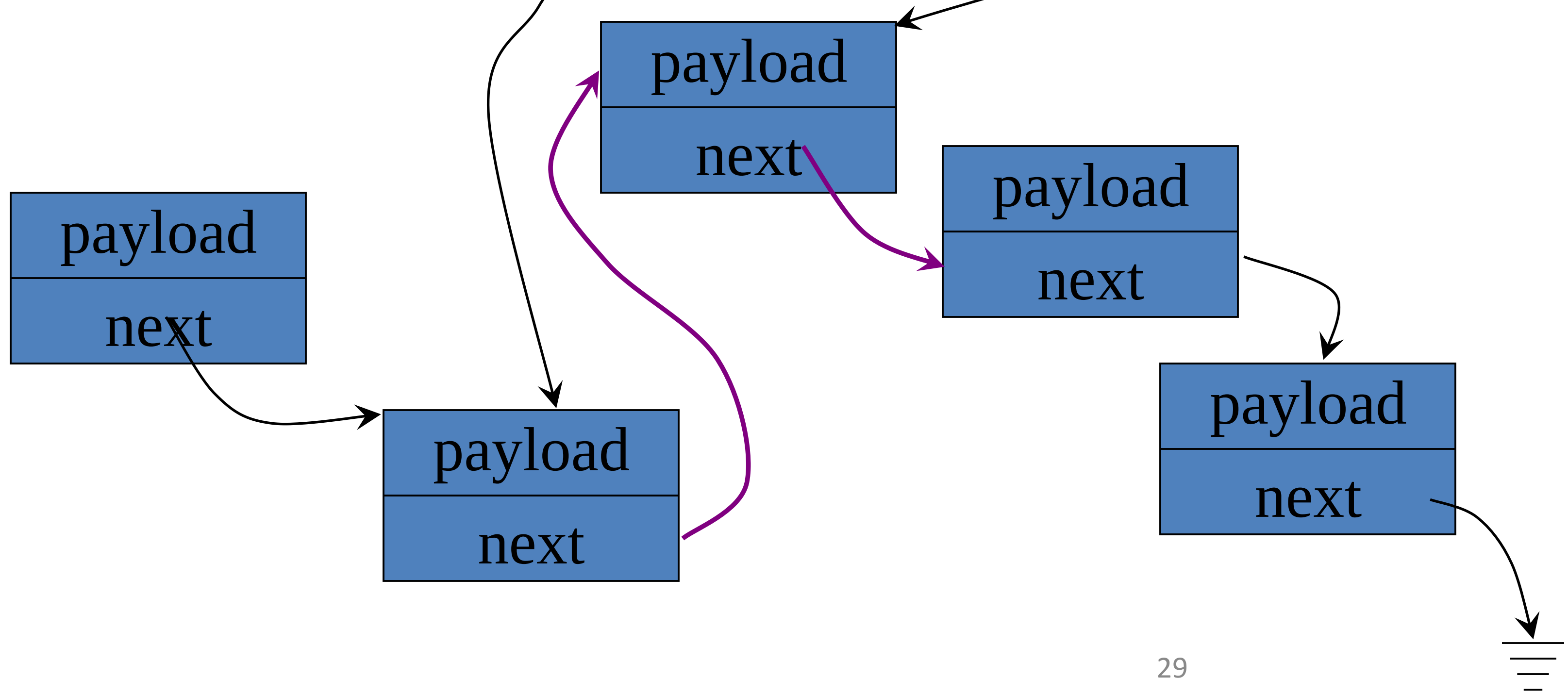
```
listItem *addAfter(listItem *p, listItem *q){
   q -> next = p -> next;
   p -> next = q;
   return p;
}
```



Adding an Item to a List

Question: What to do if we cannot guarantee that *p* and *q* are non-NULL?

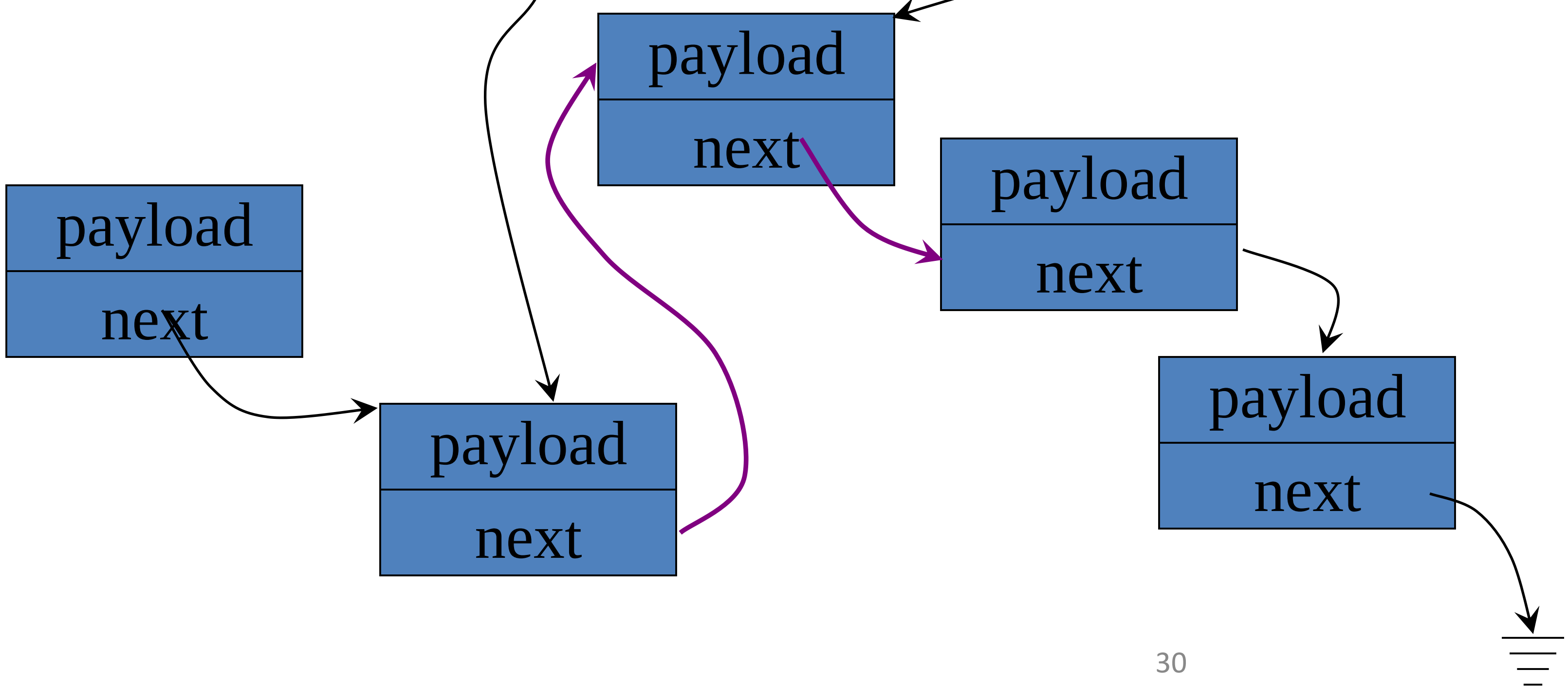
```
listItem *addAfter(listItem *p, listItem *q){
   q -> next = p -> next;
   p -> next = q;
   return p;
}
```



Adding an Item to a List (continued)

Note test for non-null *p* and *q*

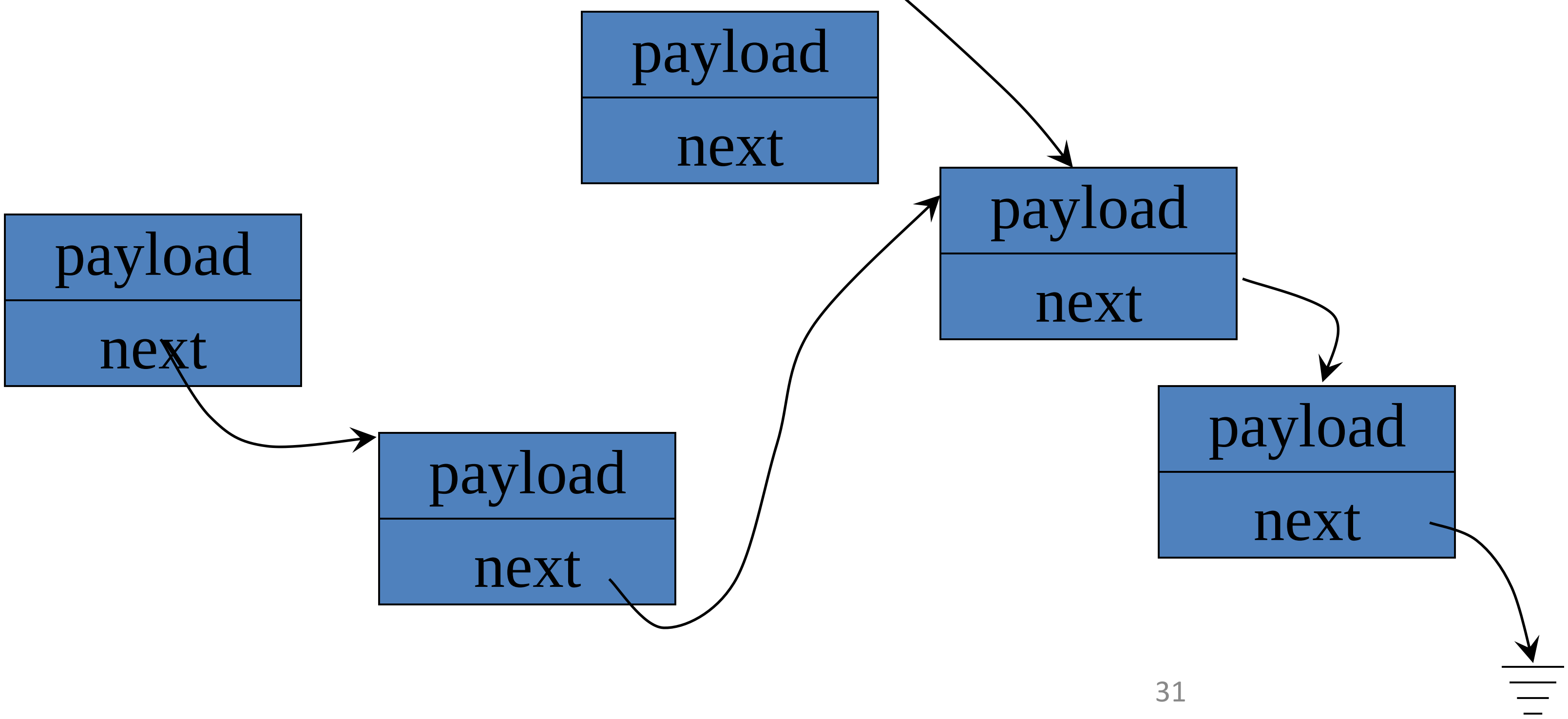
```
listItem *addAfter(listItem *p, listItem *q){
   if (p && q) {
        q -> next = p -> next;
        p -> next = q;
   }
   return p;
}
```



What about Adding an Item *before* another Item?

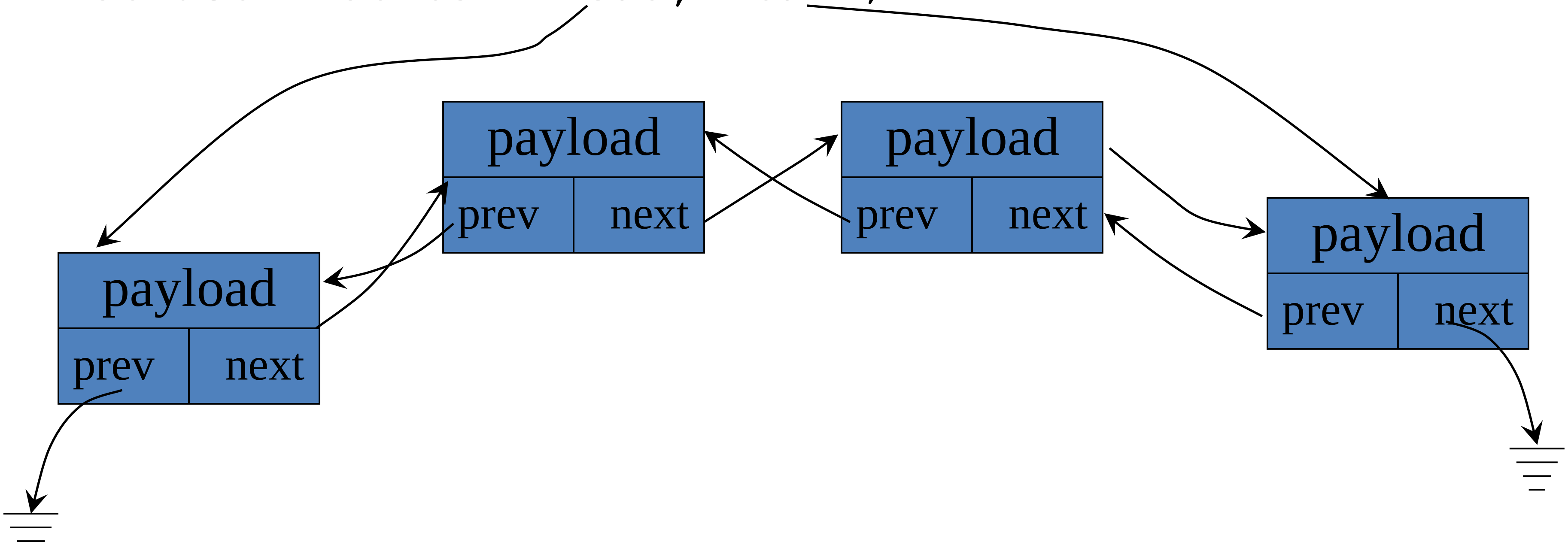
```
struct listItem *p;
```

- Add an item *before* item pointed to by **`p`** (**`p != NULL`**)



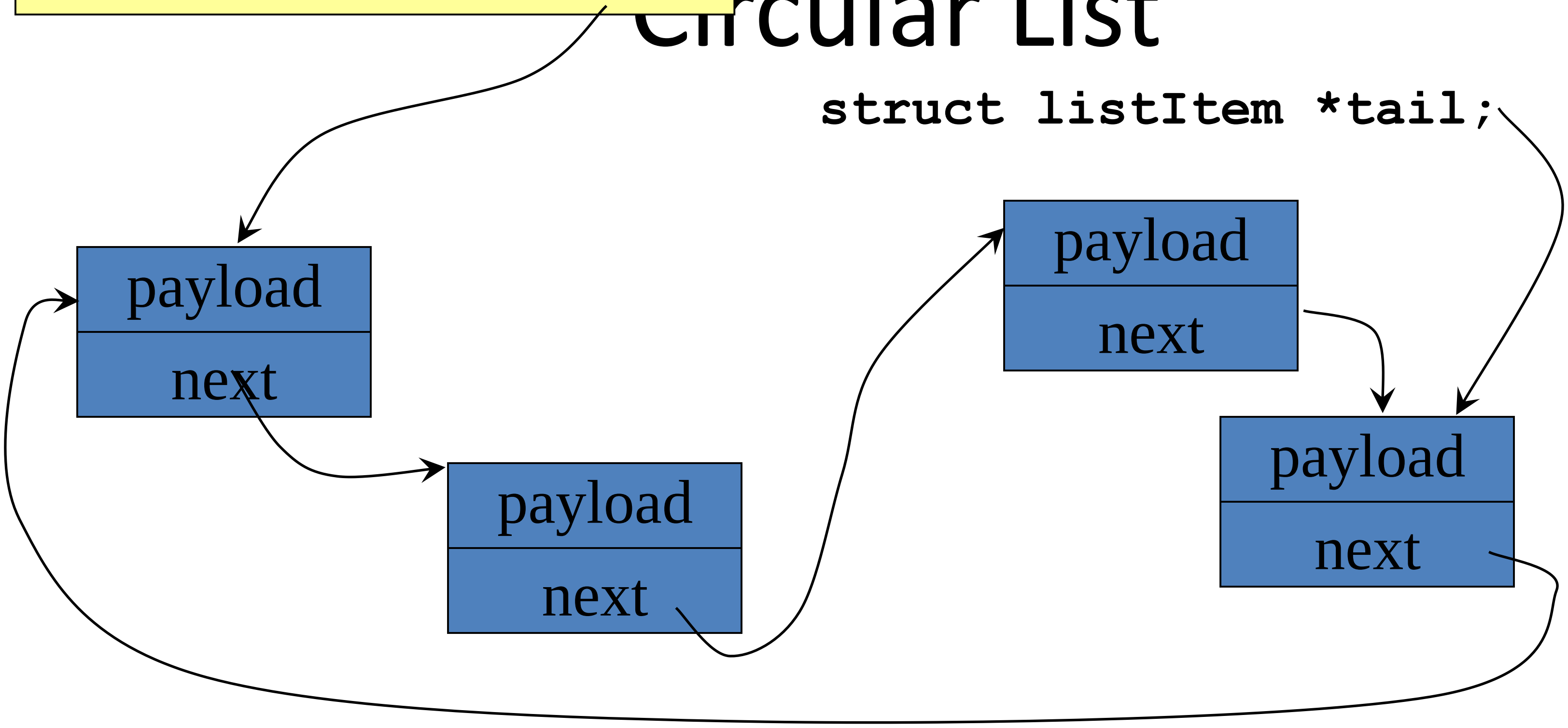
Doubly-Linked List

```
struct listItem {
   type payload;
   listItem *prev;
   listItem *next;
};
struct listItem *head, *tail;
```



Optional:–
struct listItem *head;

Circular List




```
listItem *addAfter (listItem *p, listItem *tail){
   if (p && tail) {
        p -> next = tail -> next;
        tail = p;
   } else if (p) {
        tail p -> next = p;
   }
   return tail;
}
```