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# Linked List

**Data Structures**  
**C++ for C Coders**

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Singly Linked List

## Self-referenced structures – review

**Exercise:** Link a, b and c nodes;

```
struct List {  
    string who;  
    char  data;  
    List *link;  
};
```

List **a, b, c**;

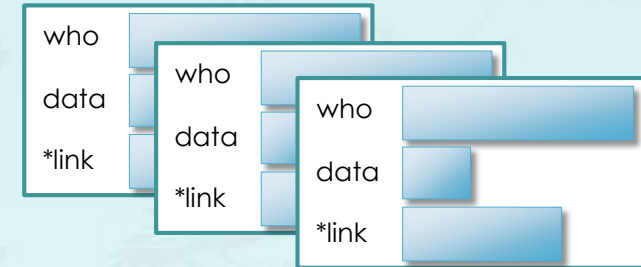
a.data = 'A';

b.data = 'B';

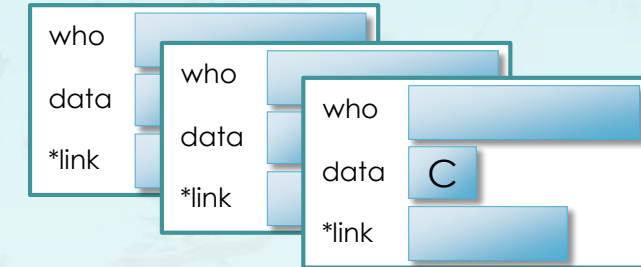
c.data = 'C';

a.link = b.link = c.link = nullptr;

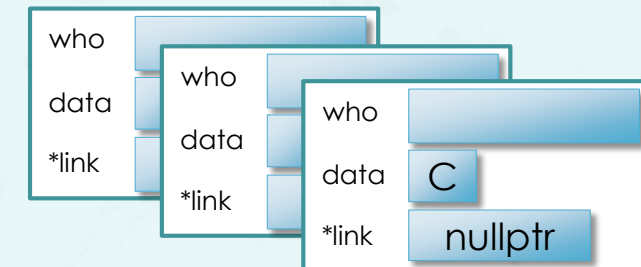
List a, b, c;



a.data = 'A';  
b.data = 'B';  
c.data = 'C';



a.link = b.link = c.link = nullptr;



## Self-referenced structures – review

**Exercise:** Link a, b and c nodes;

```
struct List {  
    string who;  
    char  data;  
    List *link;  
};
```

List **a**, **b**, **c**;

a.data = 'A';

b.data = 'B';

c.data = 'C';

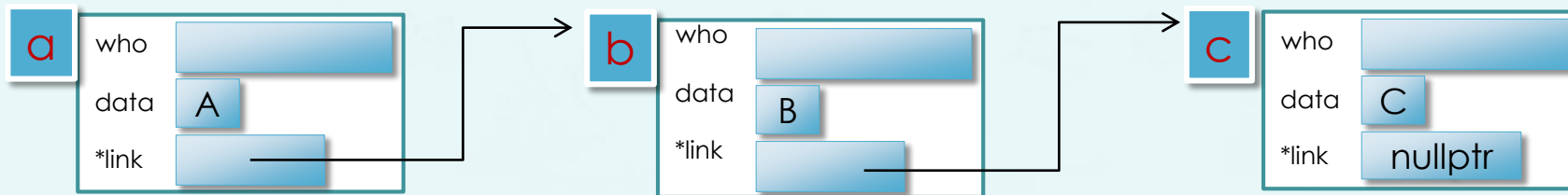
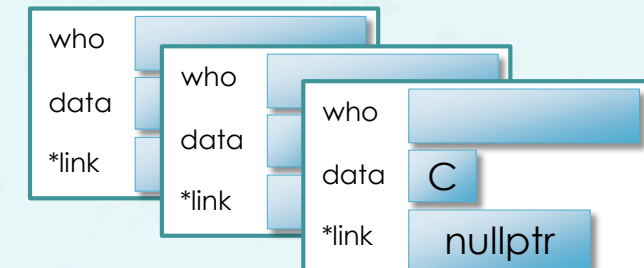
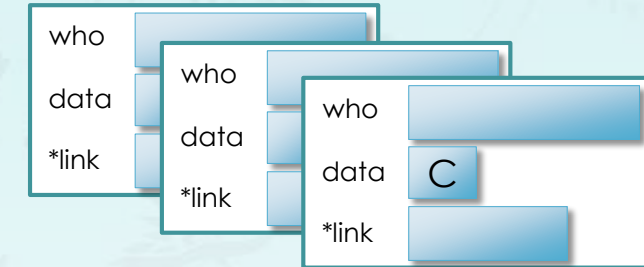
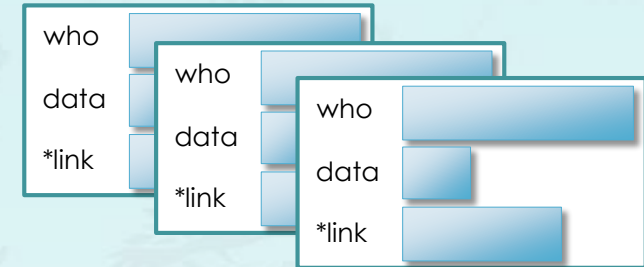
a.link = b.link = c.link = nullptr;

```
_____  
____;
```

List a, b, c;

a.data = 'A';  
b.data = 'B';  
c.data = 'C';

a.link = b.link = c.link = nullptr;



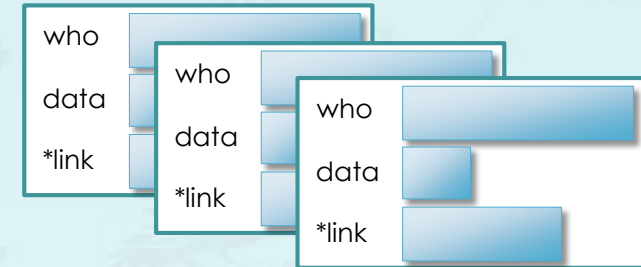
## Self-referenced structures – review

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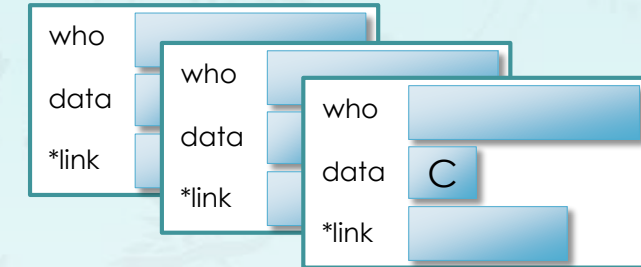
```
struct List {  
    string who;  
    char  data;  
    List *link;  
};
```

```
List a, b, c;  
List *p, *q, *r;
```

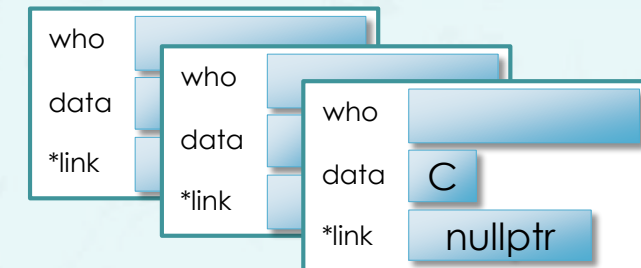
List a, b, c;



a.data = 'A';  
b.data = 'B';  
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a.link = b.link = c.link = nullptr;



# Self-referenced structures – review



**Exercise:** Link a, b and c nodes;

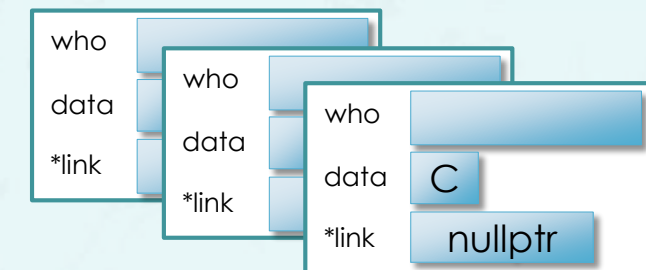
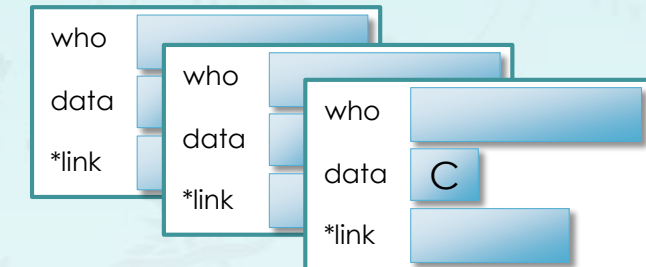
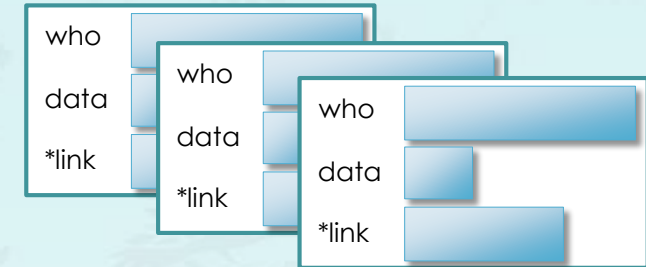
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    List *link;  
};
```

```
List a, b, c;  
List *p, *q, *r;
```

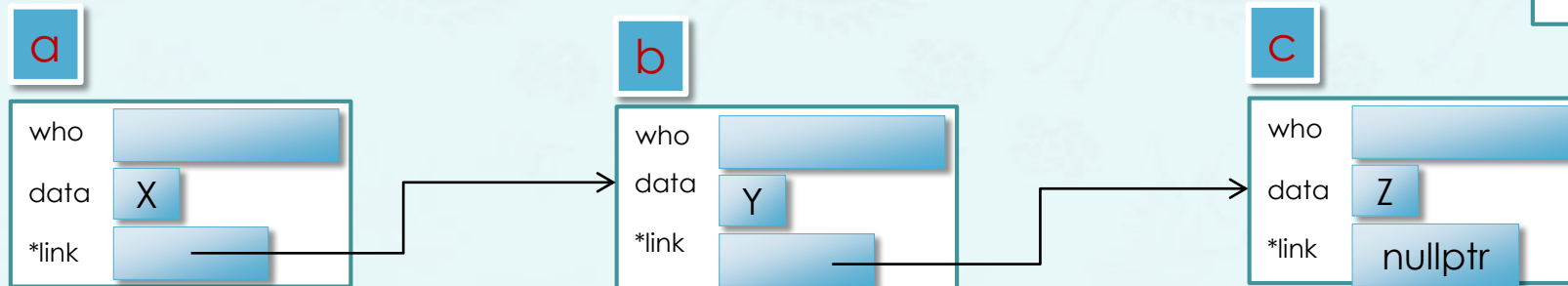
(1)

(2)

(3)

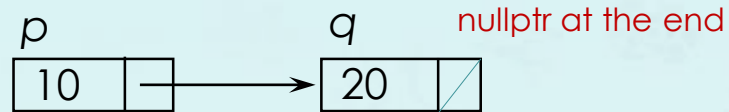


- (1) Let each p, q, and r points to a, b, and c;
- (2) Store each 'X', 'Y', and 'Z' in data
- (3) Connect them using p, q and r as shown below:



# Linked List

**TASK:** Code a function that returns the head of following linked list.



```
struct Node {
    int data;
    Node* next;
};
using pNode = Node*;
```

Write a function that creates a node and returns **pNode**.

```
pNode newNode(int val) {
    pNode node = (pNode)malloc(sizeof(Node));
    node->data = val;
    node->next = nullptr;
    return node;
}
```

**C**

```
pNode newNode(int val) {
    pNode node = new Node;
    node->data = val;
    node->next = nullptr;
    return node;
}
```

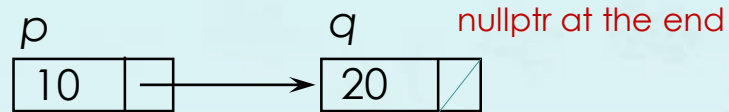
**C++**

```
pNode node = new Node {0, nullptr};
```

**C++**

## Linked List

**TASK:** Code a function that returns the head of following linked list.



```
struct Node {  
    int data;  
    Node* next;  
};  
using pNode = Node*;
```

```
pNode newList2(int a, int b) {  
    pNode p = new Node {a, nullptr};  
    pNode q = new Node {b, nullptr};  
    p->next = q;  
    return p;  
}
```

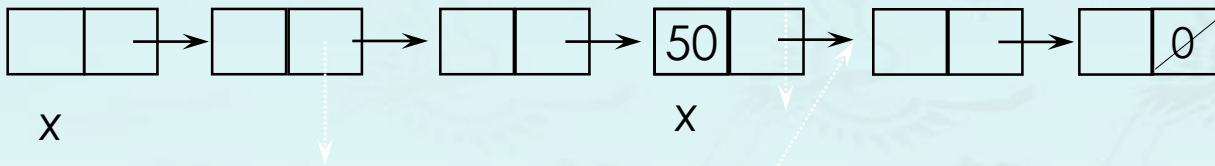
```
pNode newList2(int a, int b) {  
    pNode q = new Node {a, nullptr};  
    pNode p = new Node {b, q};  
    return p;  
}
```

```
pNode newList2(int a, int b) {  
    pNode q = new Node {a, nullptr};  
    return new Node {b, q};  
}
```

## Linked List – find()

**TASK:** Code a function that returns the first node **data = 50** if any, otherwise nullptr.

*list*



```
pNode find(pNode list, int val)
if (empty(list)) return nullptr;

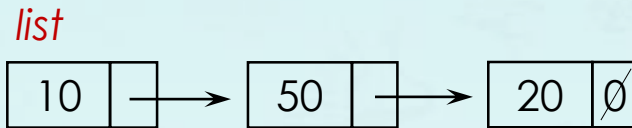
pNode x = list
while (x != nullptr) {
    if (x->data == val) return x;
    x = x->next;
}
return x;
```

```
bool empty(pNode list)
return list == nullptr;
```

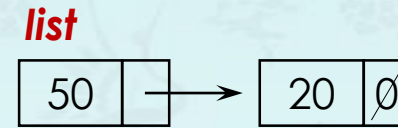


## Linked List – pop\_front()

**TASK:** Code a function that deletes the first node and returns the new first node.



(before)



(after)

```
pNode pop_front(pNode list)
if (empty(list)) return list;

list = list->next;
return list;
```

What's wrong?

```
pNode pop_front(pNode list)
if (empty(list)) return list;

pNode x = list;
list = list->next;
delete x;
return list;
```

## Linked List – **push\_front()**

**TASK:** Code a function that add a node at the beginning of the list.  
- If the list is empty, the new node becomes the head node.

*list*



*list*



*node*



*list*



```
pNode push_front(pNode list, int val)
```

```
if (empty(list))  
    return new Node{val, nullptr};
```

```
pNode node = new Node{val, nullptr};
```

## Linked List – **push\_front()**

**TASK:** Code a function that add a node at the beginning of the list.  
- If the list is empty, the new node becomes the head node.

*list*



*list*



*node*

*list*



```
pNode push_front(pNode list, int val)
```

```
if (empty(list))  
    return new Node{val, nullptr};
```

```
pNode node = new Node{val, nullptr};
```

```
node->next = list;
```

```
return node;
```

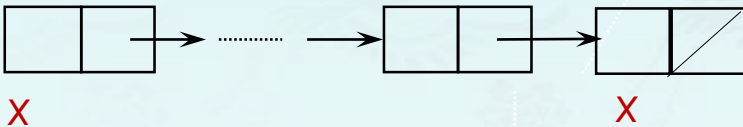
## Linked List – **push\_back()**

**TASK:** Code a function that appends a node at the end of the list.  
- If the list is empty, the new node becomes the head node.

*list*



*list*



```
pNode last(pNode list)
```

```
pNode x = list;  
while (x != nullptr)  
    x = x->next;  
return x'
```

```
pNode push_back(pNode list, int val)
```

```
if (empty(list))  
    return new Node{val, nullptr};
```

```
pNode last(pNode list)
```

```
pNode x = list;  
while (x->next != nullptr)  
    x = x->next;  
return x;
```

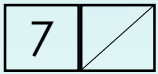
**Q:** Which one is correct?

## Linked List – insert()

**TASK:** Code a function that inserts a node(5) **at a node position x** specified by a value(7).

- If the first node(or **head**) is the position, then just invoke **push\_front()**.
- As observed below, we must to know **the pointer x** which is stored in the **previous node** of node x.

*list*



(before)

*node*



*list*



(after)

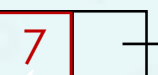
*list*



*prev*

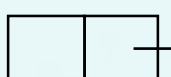


*curr*

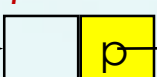


(before)

*list*



*prev*



*p*



*curr*



(after)

```
pNode insert(pNode list, int val, int x)
```

```
if (list->data == x)
```

```
pNode curr = list;  
pNode prev = nullptr;  
while (curr != nullptr) {  
    if (curr->data == x) {
```

```
        prev = curr;  
        curr = curr->next;  
    }  
    return list;
```

## Linked List

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### ❖ resizing array vs. linked list

**Tradeoffs.** Can implement a stack with either resizing array or linked list; client can use interchangeably. Which one is better?

#### Linked-list implementation

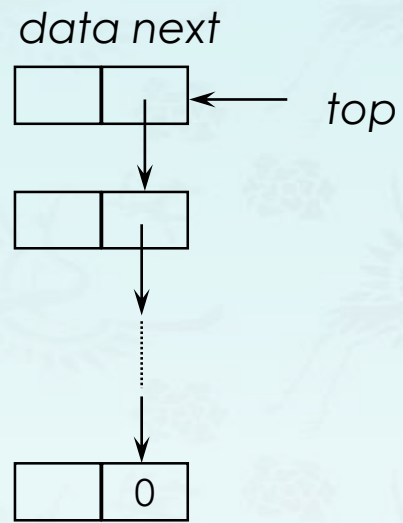
- Every operation takes constant time in the worst case.
- Uses extra time and space to deal with the links.

#### Resizing-array implementation

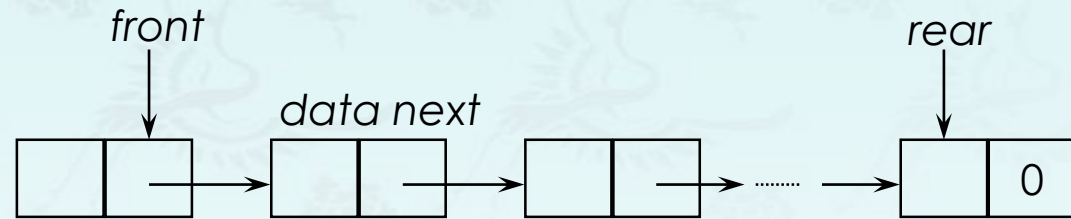
- Every operation takes constant amortized time.
- Less waste space

## Linked List

Using linked lists, **stacks** and **queues** facilitate easy insertion and deletion of nodes.



**(a) linked stack**



**(b) linked queue**

# Polynomials

## ❖ Polynomials representation

$$A(x) = a_{m-1}x^{e_{m-1}} + \dots + a_0x^{e_0}$$

$a_i$  = nonzero coefficients

$e_i$  = nonnegative integer exponents such as

$$e_{m-1} > e_{m-2} > \dots > a_0 \geq 0$$

## ❖ We may draw a **poly node** as

coef	expo	next
------	------	------

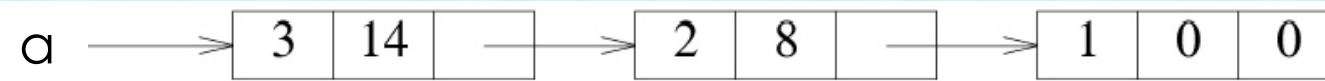
## ❖ Type definition

```
struct Poly {  
    double  coef;  
    double  expo;  
    Poly*   next;  
};  
using pPoly = Poly*;
```

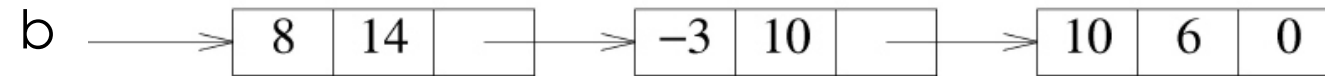


# Polynomials

## ❖ Example:



(a)  $3x^{14} + 2x^8 + 1$



(b)  $8x^{14} + 3x^{10} + 10x^6$

**Q:** How to add two polynomials?  $c = a + b$

# Polynomials

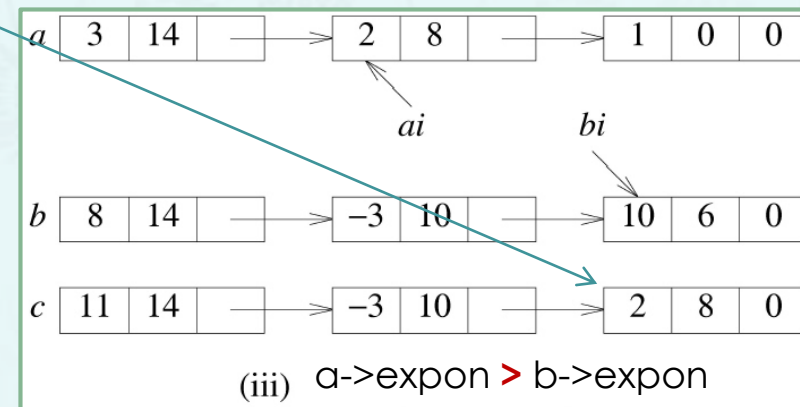
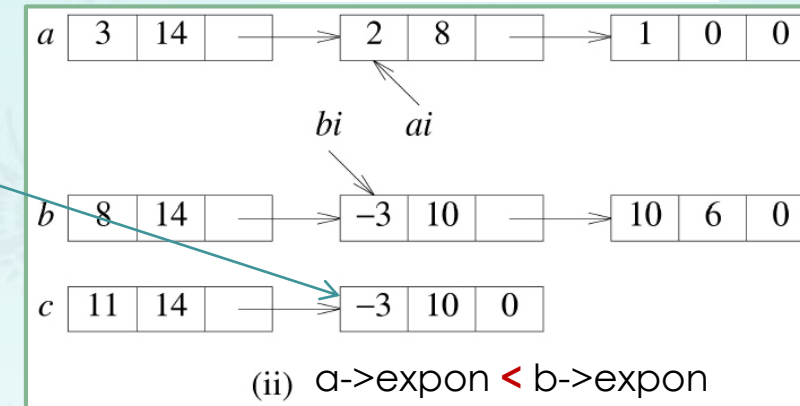
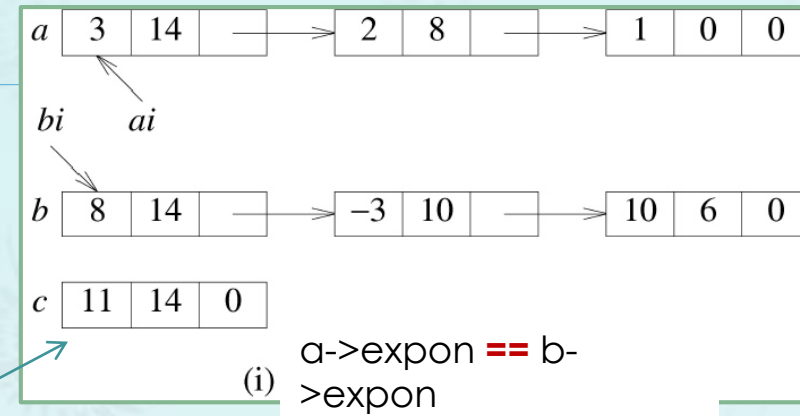
**Q: How to add two polynomials?**

$$a = 3x^{14} + 2x^8 + 1$$

$$b = 8x^{14} - 3x^{10} + 10x^6$$

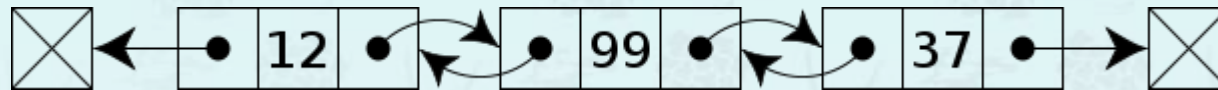
$$c = a + b$$

$$= 11x^{14} - 3x^{10} + 2x^8 + 10x^6 + 1$$



## Doubly Linked lists

- ❖ **Doubly linked list:** each node contains, besides the **next**-node link, a second link field pointing to the **previous** node in the sequence. The two links may be called **forward** and **backward**, or **next** and **prev(ious)**.



- ❖ **Type definition**

```
struct Node {
    int    data;
    Node*  prev;
    Node*  next;
};
using pNode = Node*;
```

**Q. Array vs. Singly linked list vs. Doubly linked list, Why?**

## Doubly Linked lists

---

Q. Array vs. Singly linked list vs. Doubly linked list, **Why?**

### Advantages of linked list:

- Dynamic structure (Memory Allocated at run-time)
- Have more than one data type.
- Re-arrange of linked list is easy (Insertion-Deletion).
- **It doesn't waste memory.**

### Disadvantages of linked list:

- In linked list, if we want to access any node it is difficult.
- **It uses more memory.**

### Advantages of doubly linked list:

- A doubly linked list can be **traversed in both directions** (forward and backward). A singly linked list can only be traversed in one direction.
- Most operations are  $O(1)$  instead of  $O(n)$ .

## Pointer Linked – Lab

```
#include <iostream>
using namespace std;
class Node {
public:
    char ch;
    Node* next;
};

int main( ) {
    Node* p = nullptr, *q = nullptr;
    char ch;
    while (cin.get(ch) && ch != '\n') {
        p = new Node;
        p->ch = ch;
        p->next = q;
        q = p;
    }
    while (p != nullptr) {
        cout.put(p->ch);
        p = p->next;
    }
    cout << endl;
}
```

## Pointer Linked – Lab

```
#include <iostream>
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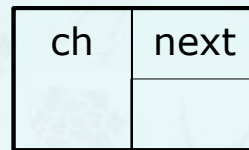
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        q = p;
    }
    while (p != nullptr) {
        cout.put(p->ch);
        p = p->next;
    }
    cout << endl;
}
```

Assuming the input A, B, C, D to this program, what would be the data structure after the input?

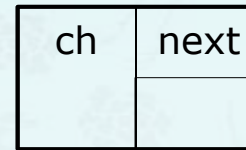
Draw a figure to represent the data structure in memory. Use a mnemonic memory address to represent each node such as A2, B5, C1, ..., etc.



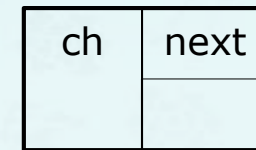
p  
D3



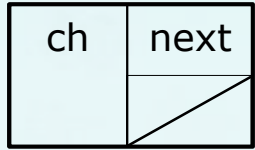
C1



B5



A2



q

**What is missing in the figure?**

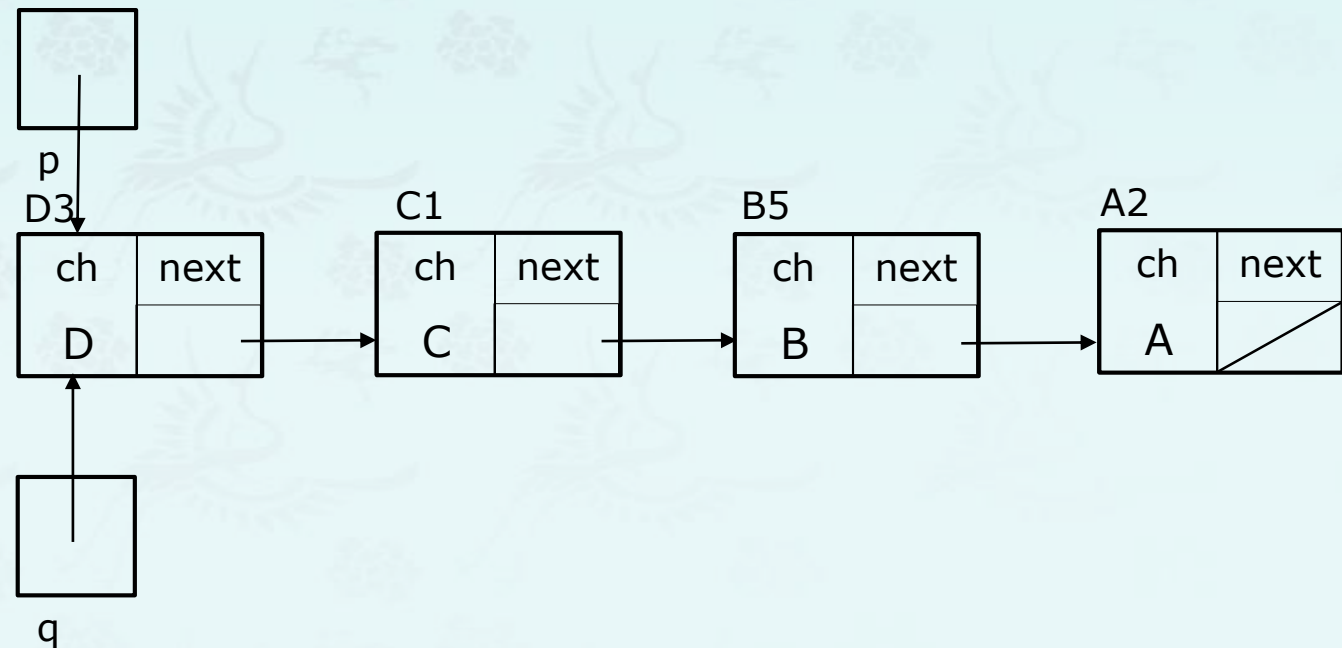
## Pointer Linked

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        p->ch = ch;
        p->next = q;
        q = p;
    }
    while (p != nullptr) {
        cout.put(p->ch);
        p = p->next;
    }
    cout << endl;
}
```

Assuming the input A, B, C, D to this program, what would be the data structure after the input?

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**What is missing in the figure?**

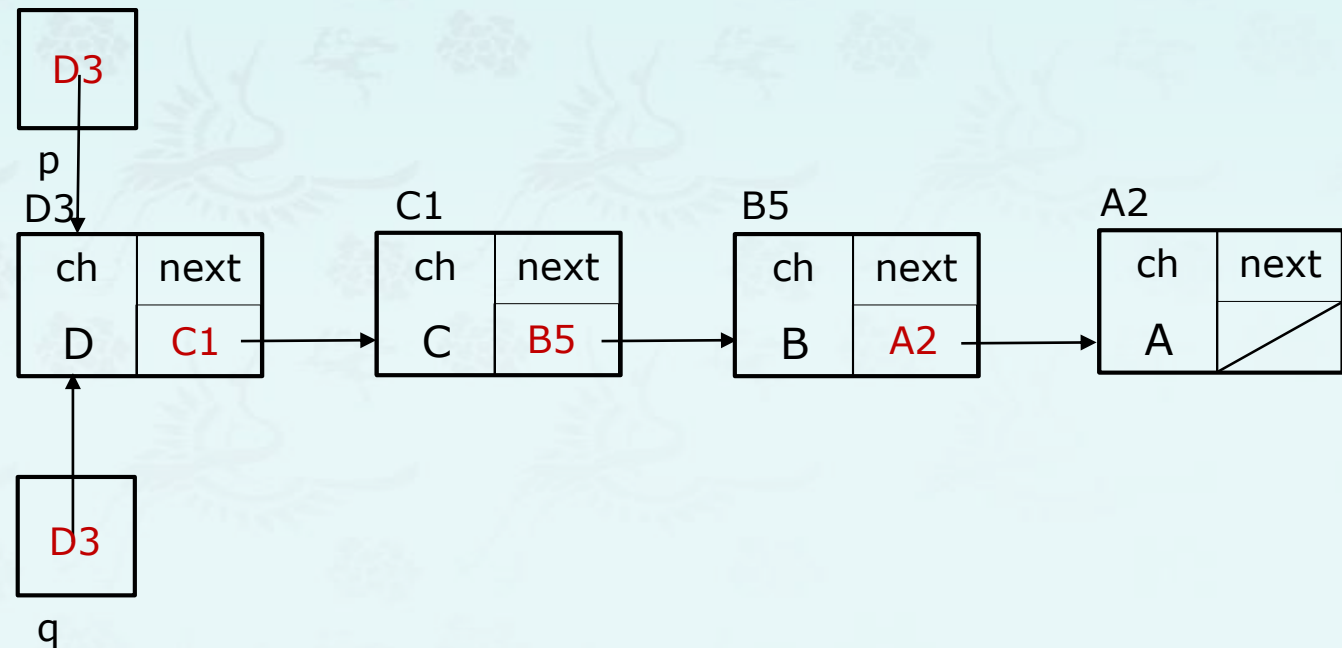
## Pointer Linked

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    Node* next;
};

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    char ch;
    while (cin.get(ch) && ch != '\n') {
        p = new Node;
        p->ch = ch;
        p->next = q;
        q = p;
    }
    while (p != nullptr) {
        cout.put(p->ch);
        p = p->next;
    }
    cout << endl;
}
```

Assuming the input A, B, C, D to this program, what would be the data structure after the input?

Draw a figure to represent the data structure in memory. Use a mnemonic memory address to represent each node such as A2, B5, C1, ..., etc.





## Pointer Linked

```
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public:
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};

int main( ) {
    Node* p = nullptr, *q = nullptr;
    char ch;
    while (cin.get(ch) && ch != '\n') {
        p = new Node;
        p->ch = ch;
        p->next = q;
        q = p;
    }
    while (p != nullptr) {
        cout.put(p->ch);
        p = p->next;
    }
    cout << endl;
}
```

After executing the while loop,  
What is the output?  
What is the values of p and q?

