2/4

Linked List

Data Structures
C++ for C Coders

한동대학교 김영섭 교수
idebtor@gmail.com

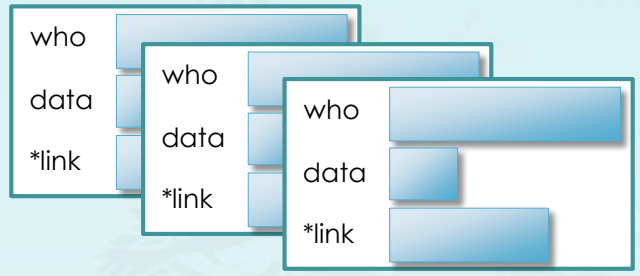
Singly Linked List

Self-referenced structures – review

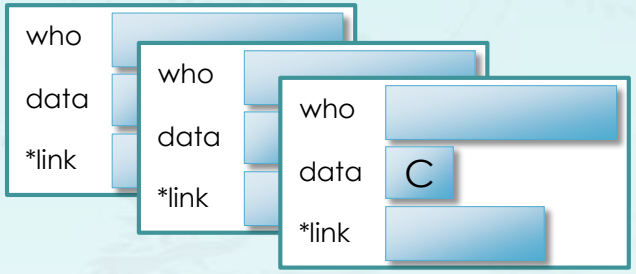
Exercise: Link a, b and c nodes;

```
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;
```

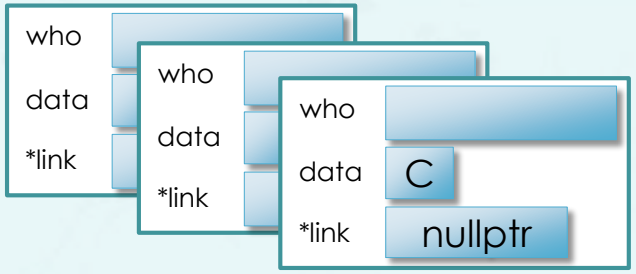
List a, b, c;



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



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

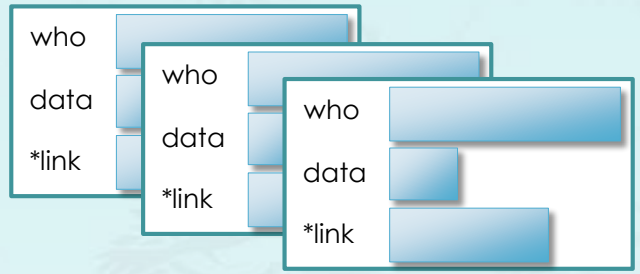


Self-referenced structures – review

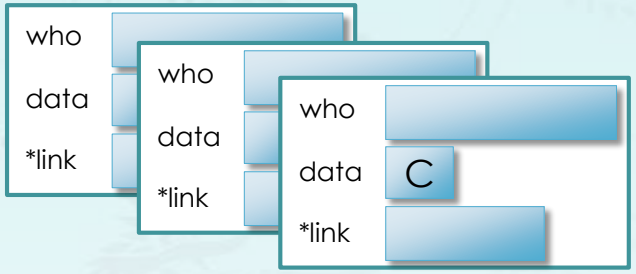
Exercise: Link a, b and c nodes;

```
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;

                    ;
                    ;
```

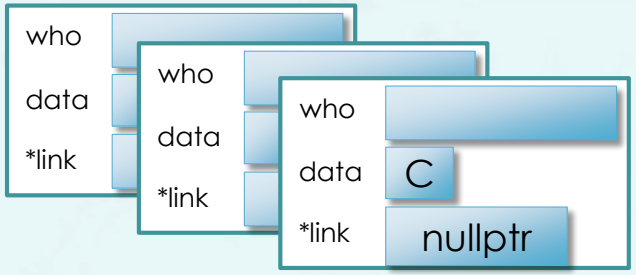
List a, b, c;

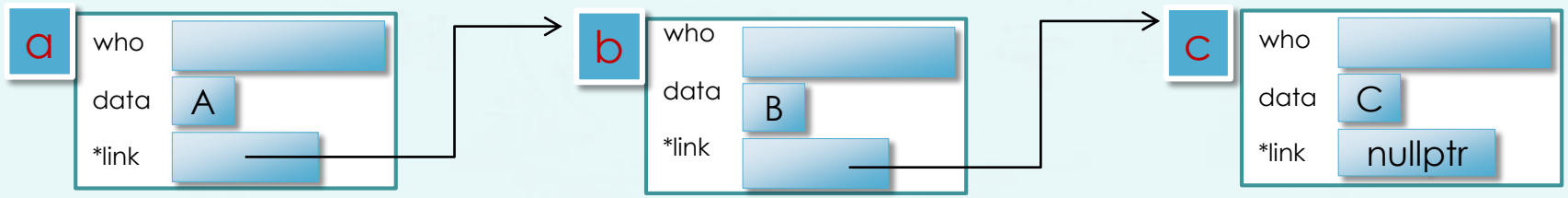



```
a.data = 'A';
b.data = 'B';
c.data = 'C';
```




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



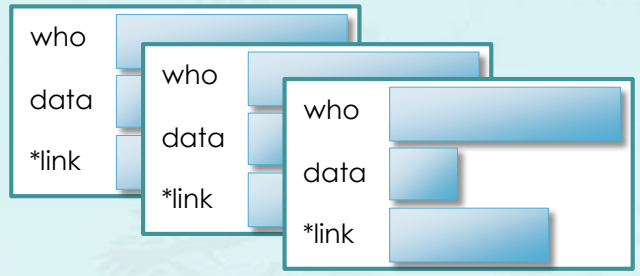


Self-referenced structures – review

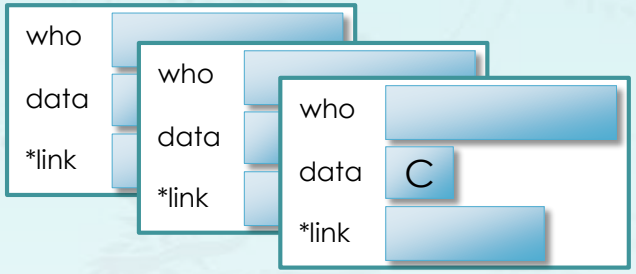
Exercise: Link a, b and c nodes;

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

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

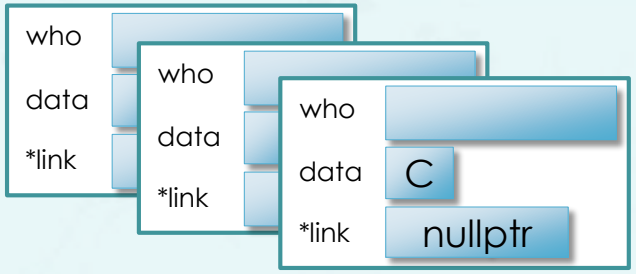
List a, b, c;



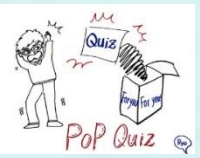
a.data = 'A';
b.data = 'B';
c.data = 'C';



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



Self-referenced structures – review



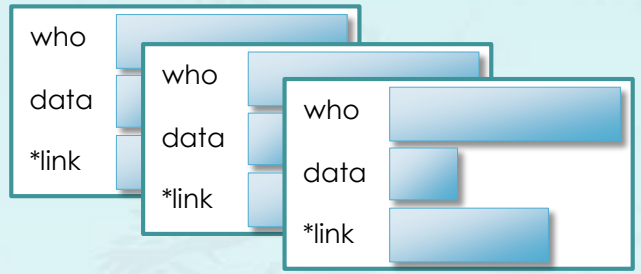
Exercise: Link a, b and c nodes;

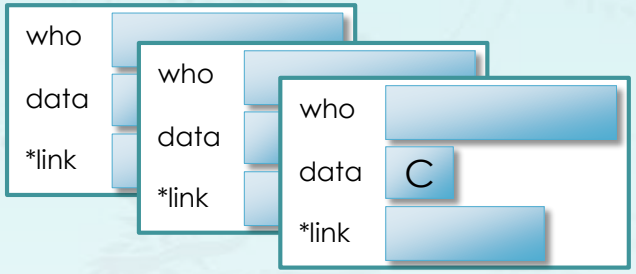
```
struct List {
        string who;
        char  data;
        List *link;
};

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

(1)

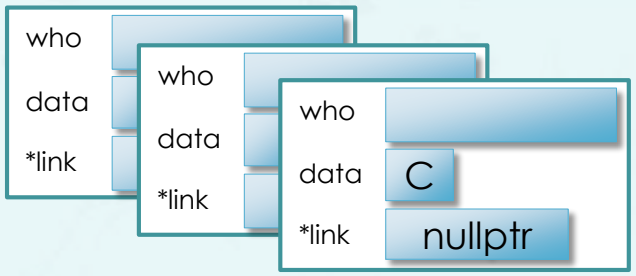
(2)

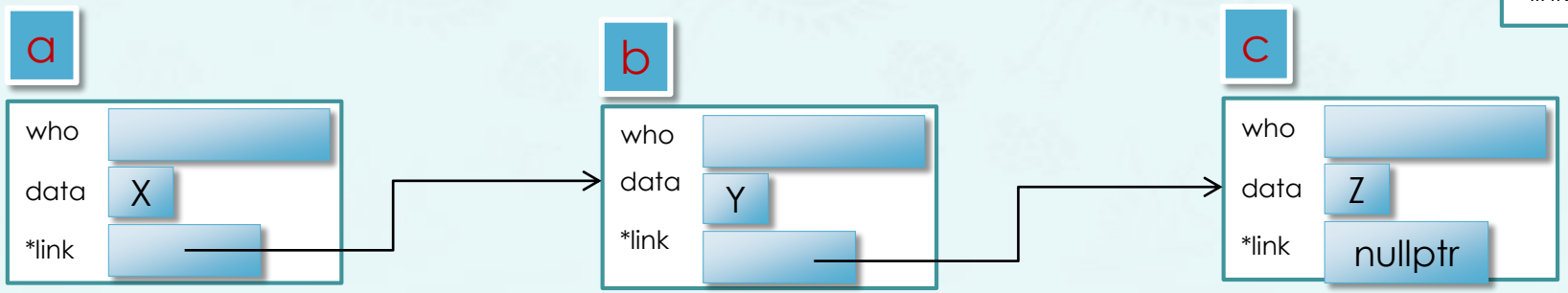
(3)





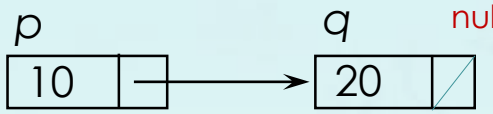
(1) Let each p, q, and r points to a, b, and c;
(2) Store each 'X', 'Y', and 'Z' in data
(3) Connect them using p, q and r as shown below:





Linked List

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



nullptr at the end

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

Write a function that creates a node and returns pNode.

C

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

C++

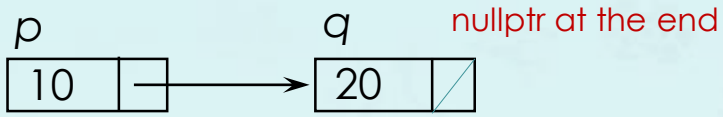
```
pNode newNode(int val) {
  pNode node = new Node;
  node->data = val;
  node->next = nullptr;
  return node;
}
```

C++

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

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 {b, nullptr};
  pNode p = new Node {a, q};
  return p;
}
```

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

Linked List – find()

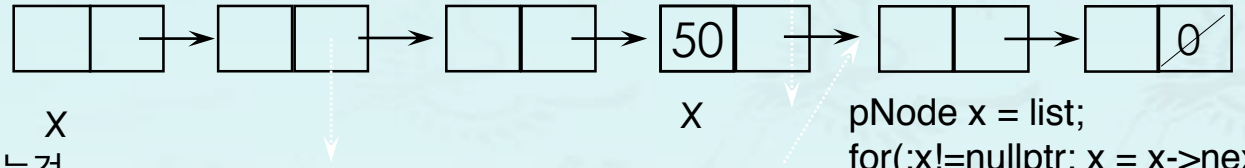
main에서 영향을 주고 싶다면
pNode를 이중 포인터로 받와야한다.
그래도 pNode x = list를 해서 copy한 다음에
하는 것을 추천

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

while (list != nullptr ) {
____________
____________
}
return list;
```

이렇게 해도 됨
여기 함수에서 사용하는 list는
main에 list에 영향을 주지 않음

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

list



이게 맞는것

```
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;
```

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

이렇게 해도됨

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

if(empty(list)) return nullptr;

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

이렇게 하면 첫번째 element는 건너뜀

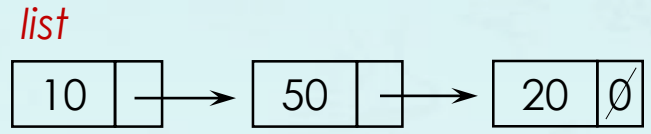
```
bool empty(pNode list)
  return list == nullptr;
```

show_all() => 여기서 이걸 쓰면 아주 좋음
list == nullptr 이 맞으면 true
틀리면 false를 바로 return

무엇이 맞을까요?

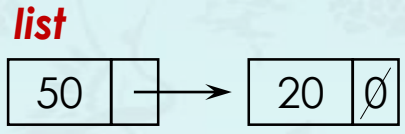
Linked List – pop_front()

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



(before)

앞에 있는 head를 없애고
head를 그 뒤로



(after)

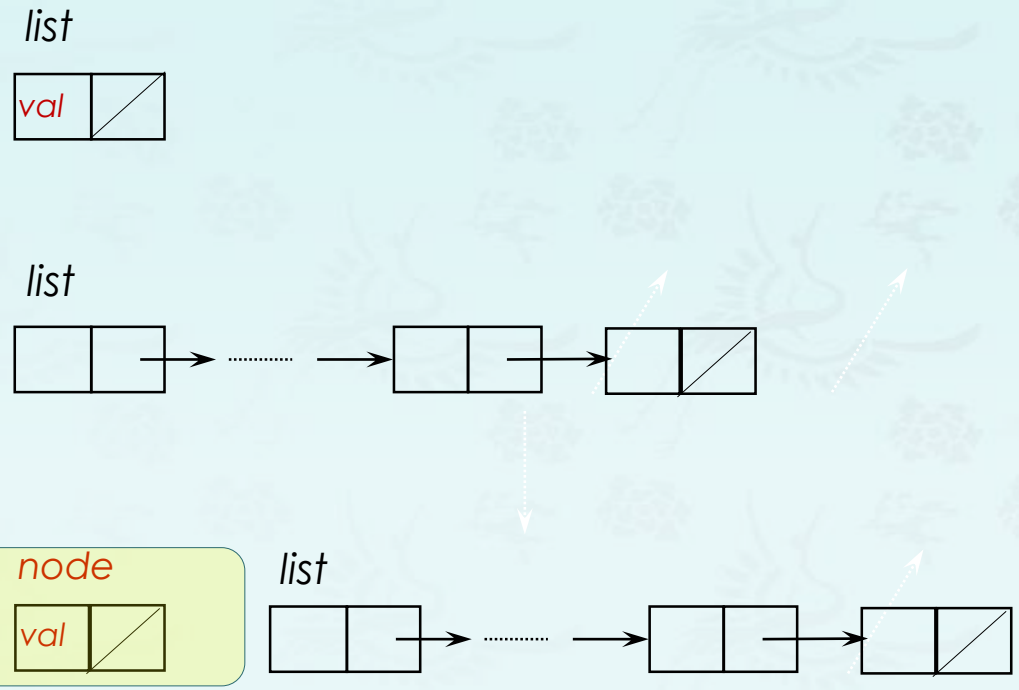
```
pNode pop_front(pNode list)
if (empty(list)) return list;

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()

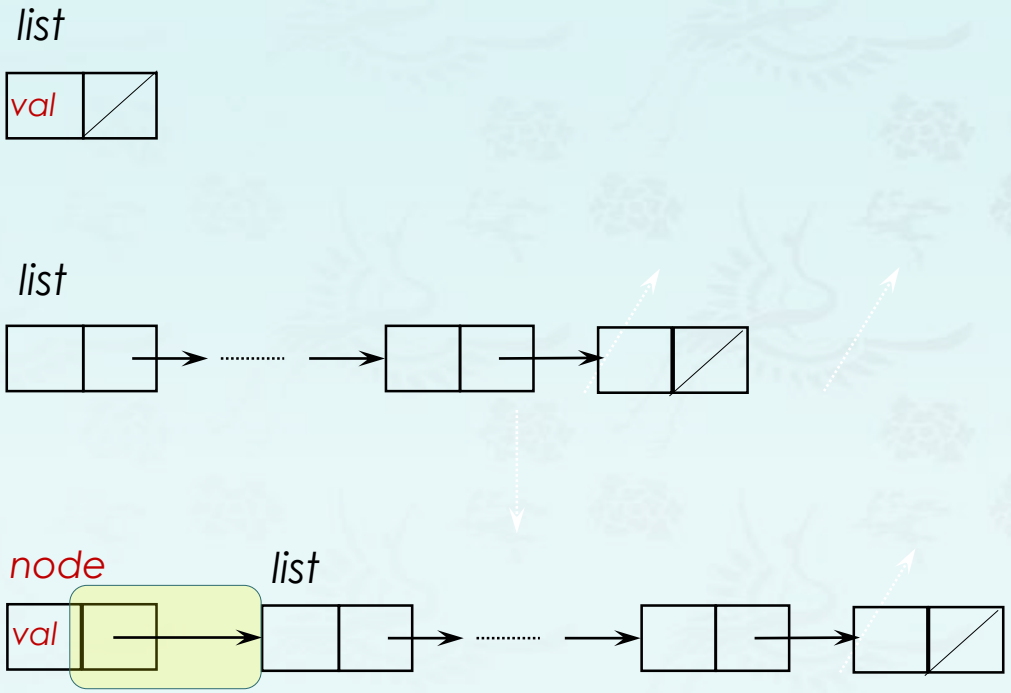
TASK: Code a function that add a node at the beginning of the list.
- If the list is empty, the new node becomes the head node.




```
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.



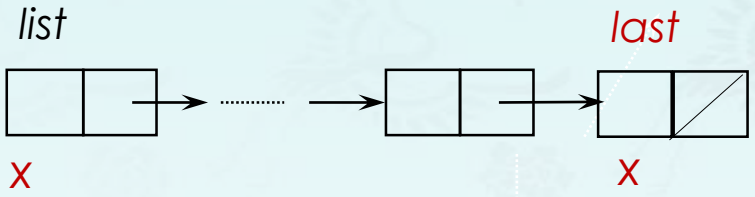

```
pNode push_front(pNode list, int val)
if (empty(list))
  return new Node{val, nullptr};

pNode node = new Node{val, nullptr};
node->next = list;
return node;
```

list

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.

while 문이 끝나면 return x; 는 결국 nullptr를 return 해 줄 수 밖에 없는 것이다.
그럼 어떻게? -> 미리 앞의 것이 nullptr이라면 그전 것을 return




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

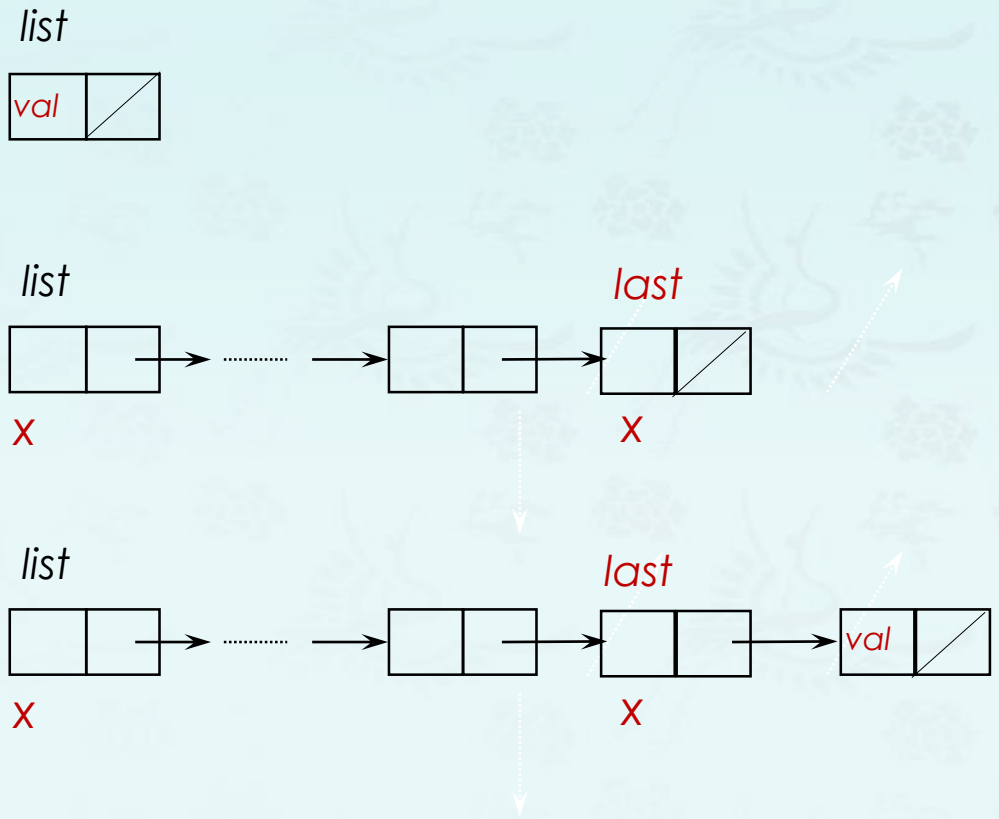
```
pNode last(pNode list)
  pNode x = list;
  while (x != nullptr)
    x = x->next;
  return x'
```

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

Q: Which one is correct?

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.



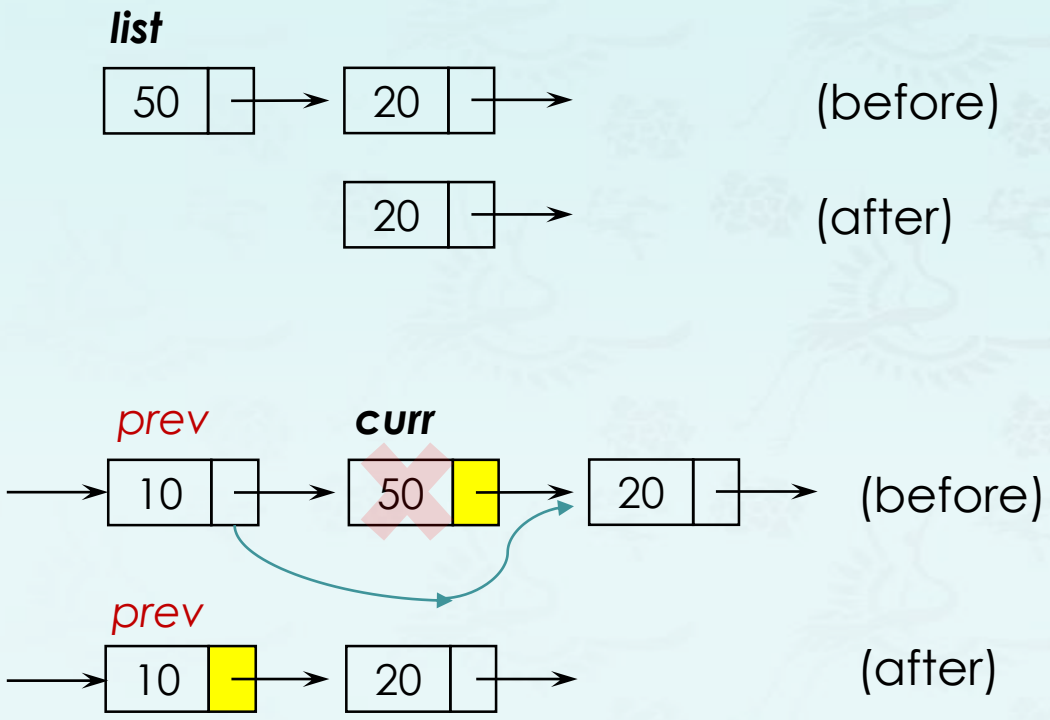

```
pNode push_back(pNode list, int val)
if (empty(list))
  return new Node{val, nullptr};
pNode x = last(list);
x -> next = new Node{val, nullptr};
return x;
return list;
```

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

Linked List – pop()

TASK: Code a function that deletes a node with a value specified.

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

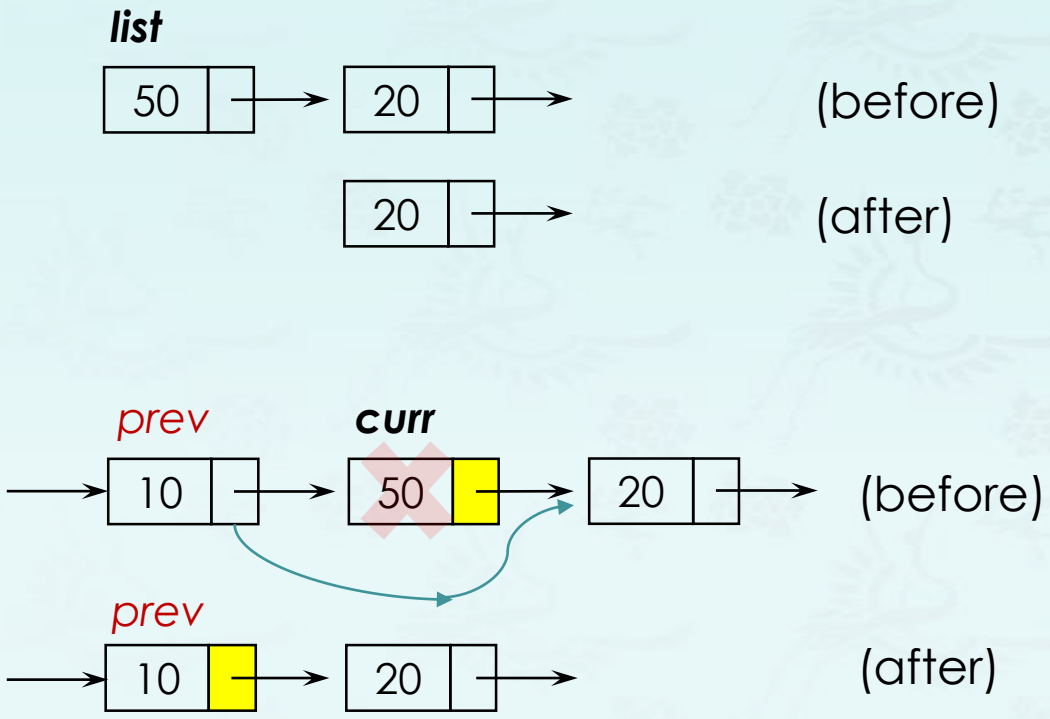



```
pNode pop(pNode list, int val)
if (list->data == val)
  return pop_front(list);

pNode curr = list;
pNode prev = nullptr;
while (curr != nullptr) {

}
return list;
```

Linked List – pop()

TASK: Code a function that deletes a node with a value specified.

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



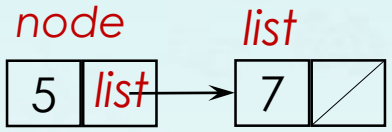

```
pNode pop(pNode list, int val)
if (list->data == val)
  return pop_front(list);

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

  }

}
return list;
```

Linked List – insert()

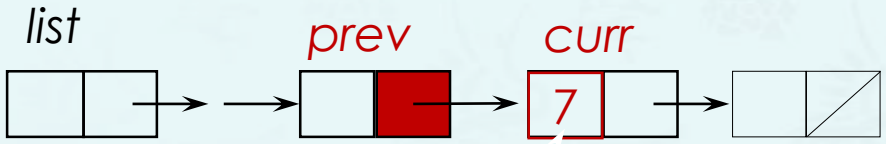
TASK: Code a function that inserts a node(5) **at a node position x** specified by a value(7).

- 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.

(before)



(after)



(before)

(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) {
    pNode  node = new Node{val, prev->next};

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

Linked List

❖ resizing array vs. linked list

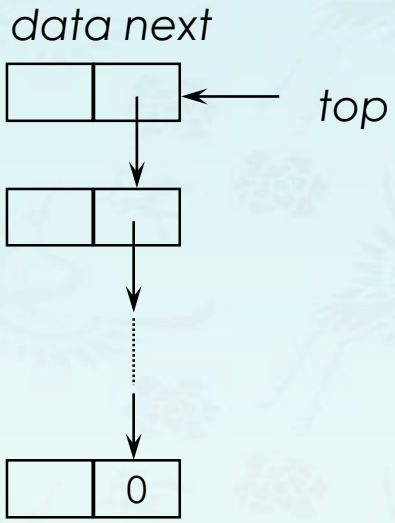
Tradeoffs. Can implement a stack with either resizing array or linked list; client can use interchangeably. Which one is better?

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

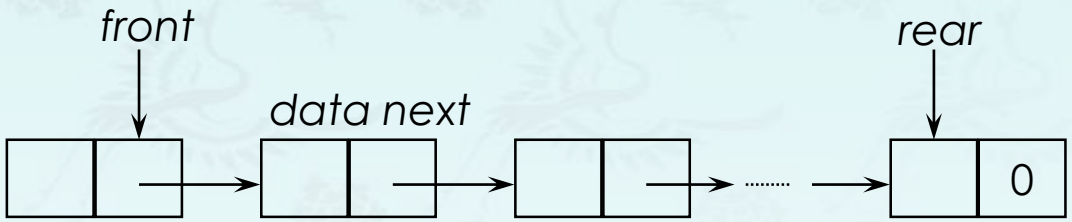
Resizing-array implementation
- Every operation takes constant amortized time.
- Less waste space

Linked List

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



(a) linked stack



(b) linked queue

Polynomials

❖ Polynomials representation

$$A(x) = a_{m-1}x^{e_{m-1}} + \cdots + a_0 x^{e_0}$$

a_i = nonzero coefficients
e_i = nonnegative integer exponents such as
$e_{m-1} > e_{m-2} > \ldots > a_0 \geq 0$

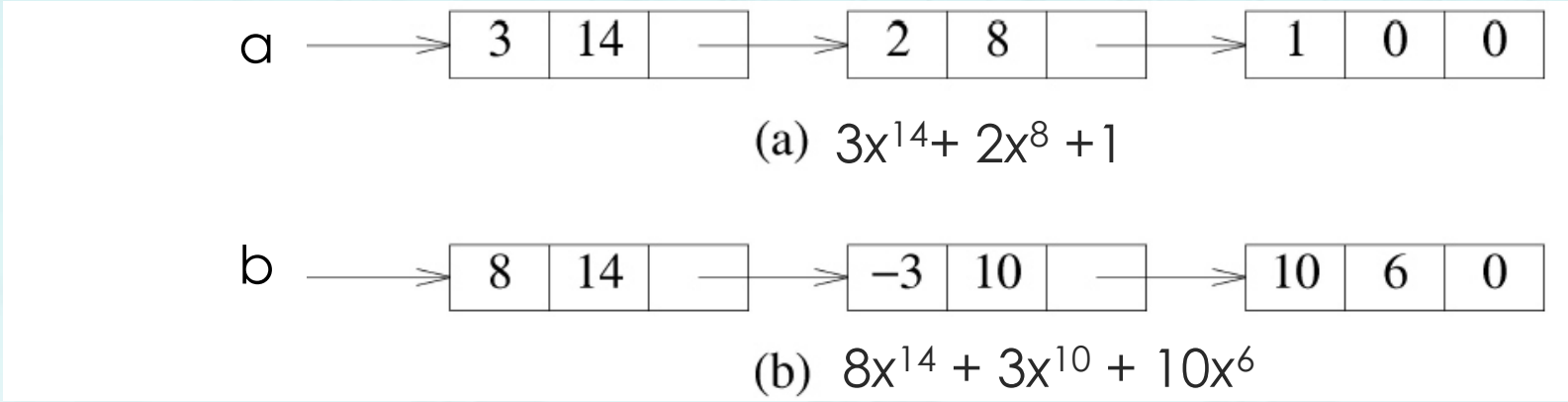
❖ We may draw a poly node as

❖ Type definition

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

Polynomials

❖ **Example:**



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

Polynomials

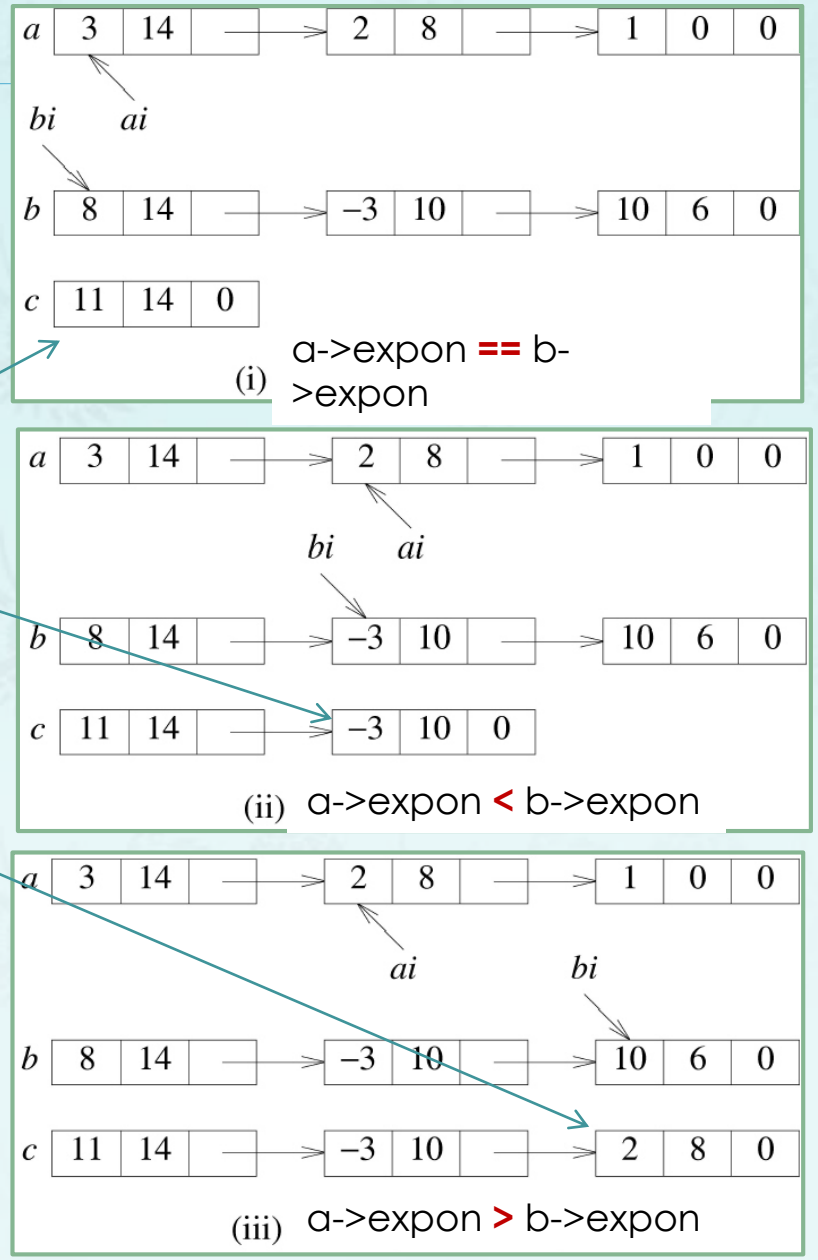
Q: How to add two polynomials?

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

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

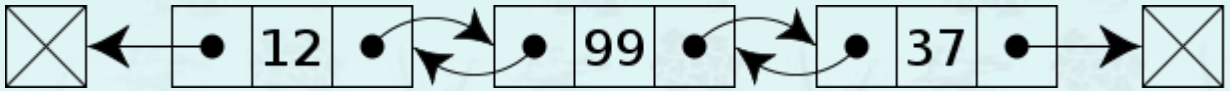
$c = a + b$

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



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

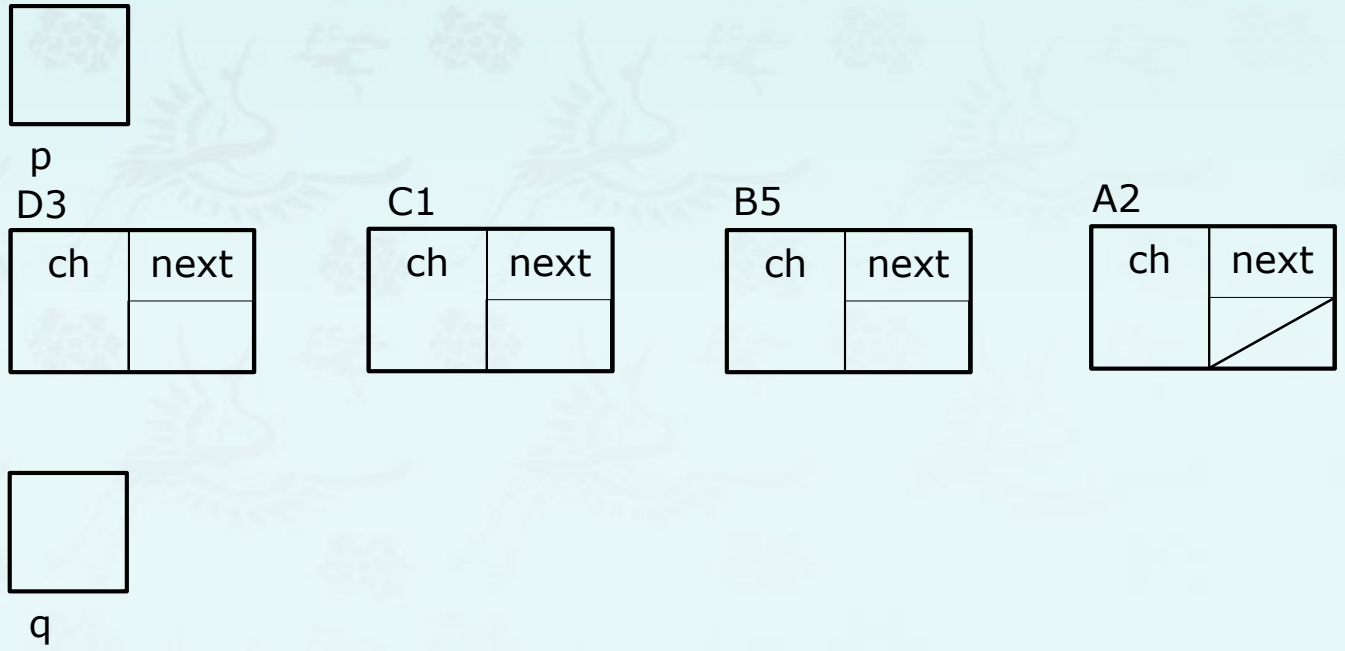
```
#include <iostream>
using namespace std;
class Node {
public:
  char ch;
  Node* next;
};

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>
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;
}
```

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.



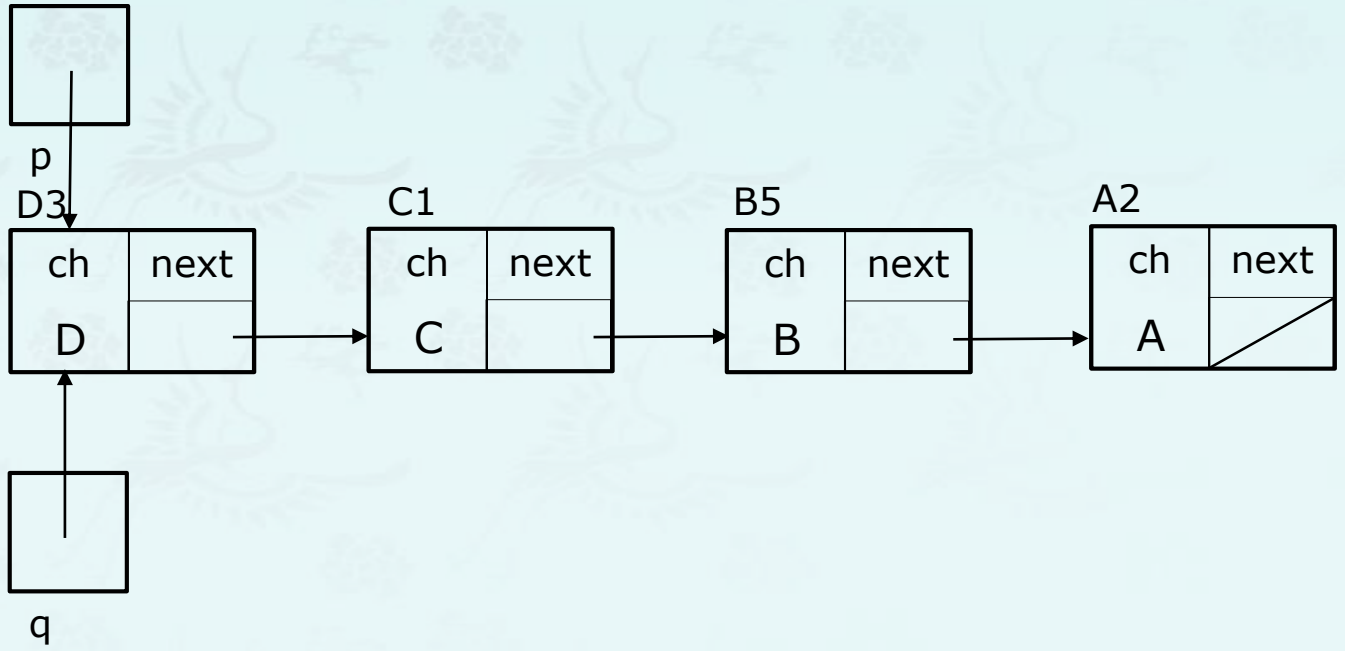
What is missing in the figure?

Pointer Linked

```
#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;
}
```

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.



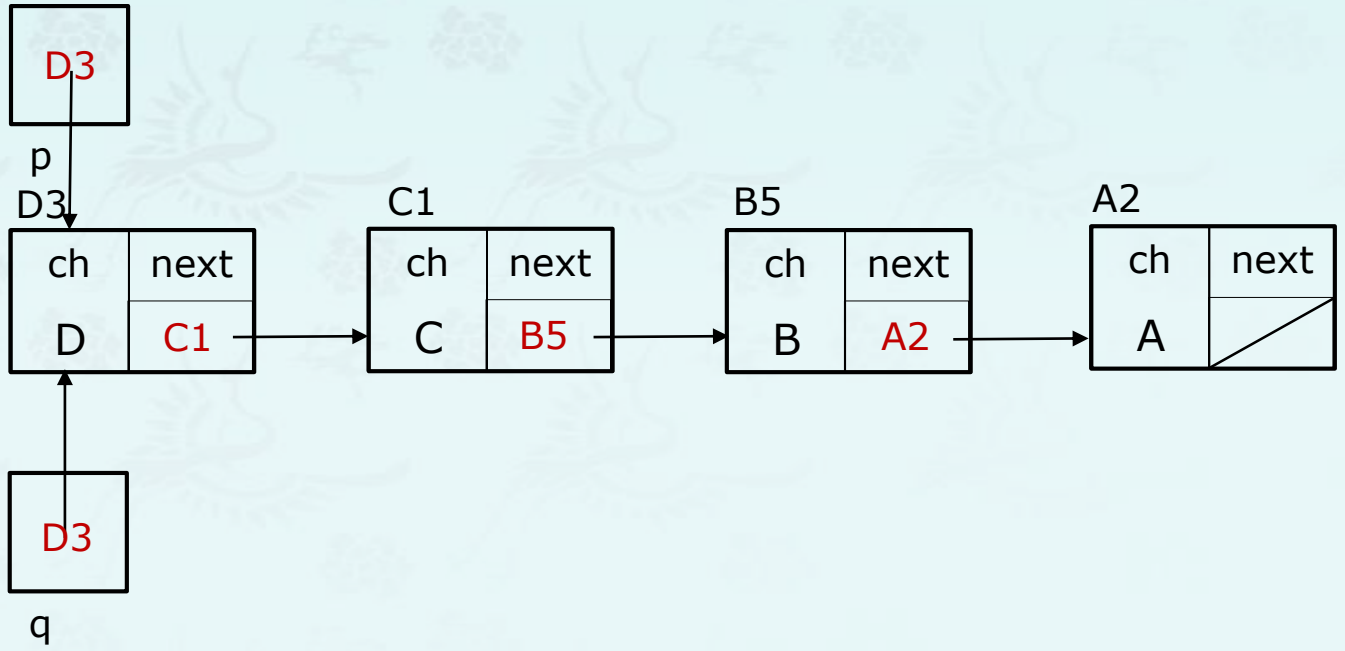
What is missing in the figure?

Pointer Linked

```
#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;
}
```

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

```
#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;
}
```

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