

3/4

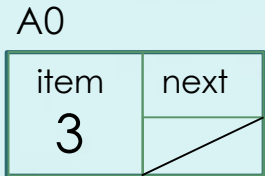
# Linked List

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

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Why doubly linked list? - An introduction

## a new node instantiation



(1) `pNode n = new Node;`

`Node* n = new Node;`

(2) `Node* n = new Node();`

(3) `Node* n = new Node{};`

(4) `Node* n = new Node(4);`

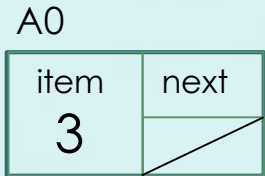
(5) `Node* n = new Node{5};`

```
struct Node {  
    int    item;           unused in  
    Node*  prev; ← singly linked  
    Node*  next;  
};
```

```
struct List {  
    Node*  head; //sentinel  
    Node*  tail; //sentinel  
    int    size; //optional  
};  
using pNode = Node*;  
using pList = List*;
```

Any invalid initialization code?

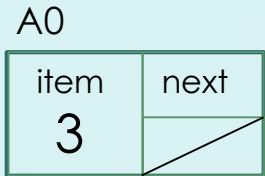
## a new node instantiation



- (1) `pNode n = new Node;`  
`Node* n = new Node;` ← no values set
- (2) `Node* n = new Node();` ← set to 0 or nullptr
- (3) `Node* n = new Node{};` ← set to 0 or nullptr
- (4) `Node* n = new Node(4);` ← Compiler error
- (5) `Node* n = new Node{5};` ← set to 5 or nullptr

```
struct Node {  
    int    item;           ← unused in  
    Node*  prev;          ← singly linked  
    Node*  next;  
};  
  
struct List {  
    Node*  head; //sentinel  
    Node*  tail; //sentinel  
    int    size; //optional  
};  
using pNode = Node*;  
using pList = List*;
```

## a new node instantiation



(1)

```
pNode n = new Node(3);
```

```
Node* n = new Node(3);
```

{2}

```
Node* n = new Node{3};
```

{3}

```
Node* n = new Node{3, nullptr};
```

{4}

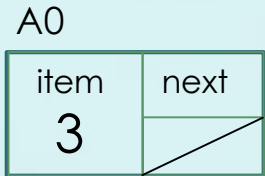
```
Node* n = new Node{3, nullptr, nullptr};
```

```
struct Node {  
    int    item;           unused in  
    Node*  prev; ← singly linked  
    Node*  next;  
};
```

```
struct List {  
    Node*  head; //sentinel  
    Node*  tail; //sentinel  
    int    size; //optional  
};  
using pNode = Node*;  
using pList = List*;
```

Any invalid initialization code?

## a new node instantiation



(1)

```
pNode n = new Node(3);
```



```
Node* n = new Node(3);
```

{2}

```
Node* n = new Node{3};
```

{3}

```
Node* n = new Node{3, nullptr};
```

{4}

```
Node* n = new Node{3, nullptr, nullptr};
```

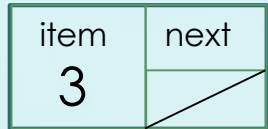
```
struct Node {  
    int    item;           unused in  
    Node*  prev; ← singly linked  
    Node*  next;  
};
```

```
struct List {  
    Node*  head; //sentinel  
    Node*  tail; //sentinel  
    int    size; //optional  
};  
using pNode = Node*;  
using pList = List*;
```

Any invalid initialization code?

## a new node instantiation

A0



```
pNode n = new Node{3};
```

```
Node* n = new Node{3};
```

```
pNode n = new Node{3, nullptr, nullptr};
```

```
Node* n = new Node{3, nullptr, nullptr};
```

```
struct Node {  
    int    item;           unused in  
    Node*  prev; ← singly linked  
    Node*  next;  
};
```

```
struct List {  
    Node*  head; //sentinel  
    Node*  tail; //sentinel  
    int    size; //optional  
};  
using pNode = Node*;  
using pList = List*;
```

```
struct Node{  
    int item;  
    Node* prev;  
    Node* next;  
    // constructor can be omitted  
    Node(int d=0, Node* p=nullptr, Node* x=nullptr) {  
        item = d;    prev = p;    next = x;  
    }  
    // destructor  
    ~Node() {}  
};
```

## linking two nodes

Task: Link two nodes and set the first node as `head`.



```
pNode head = new Node{3};  
pNode node = new Node{5};  
head->next = node;  
  
pList list = new List{head, node};
```

```
struct Node {  
    int    item;  
    Node*  prev;  
    Node*  next;  
};  
  
struct List {  
    Node*  head; //sentinel  
    Node*  tail; //sentinel  
    int    size; //optional  
};  
  
using pNode = Node*;  
using pList = List*;
```

## Node structure initialization

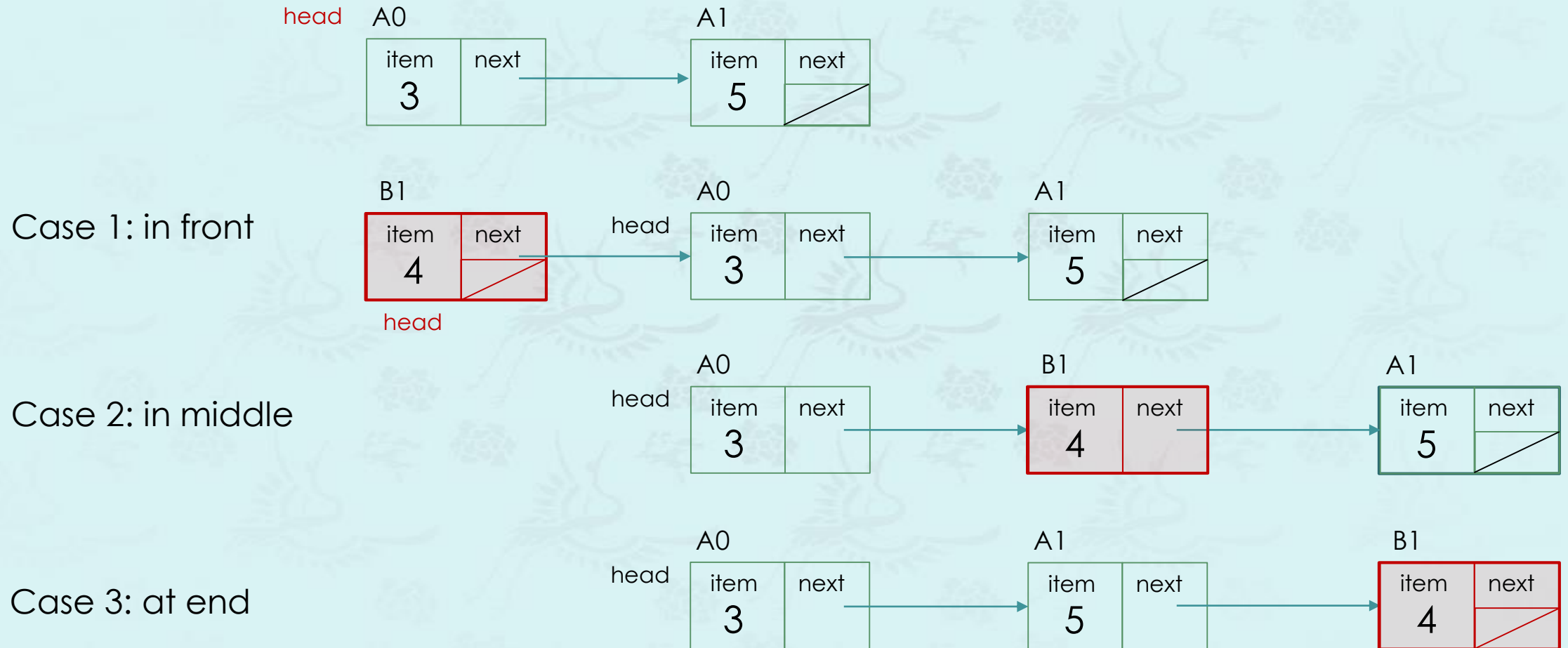
```
struct Node {  
    int      item;  
    Node*    prev;  
    Node*    next;  
    Node(const int d = 0, Node* p = nullptr, Node* x = nullptr) {  
        item = d; prev = p; next = x;  
    }  
    ~Node() {}  
};  
using pNode = Node*;
```

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

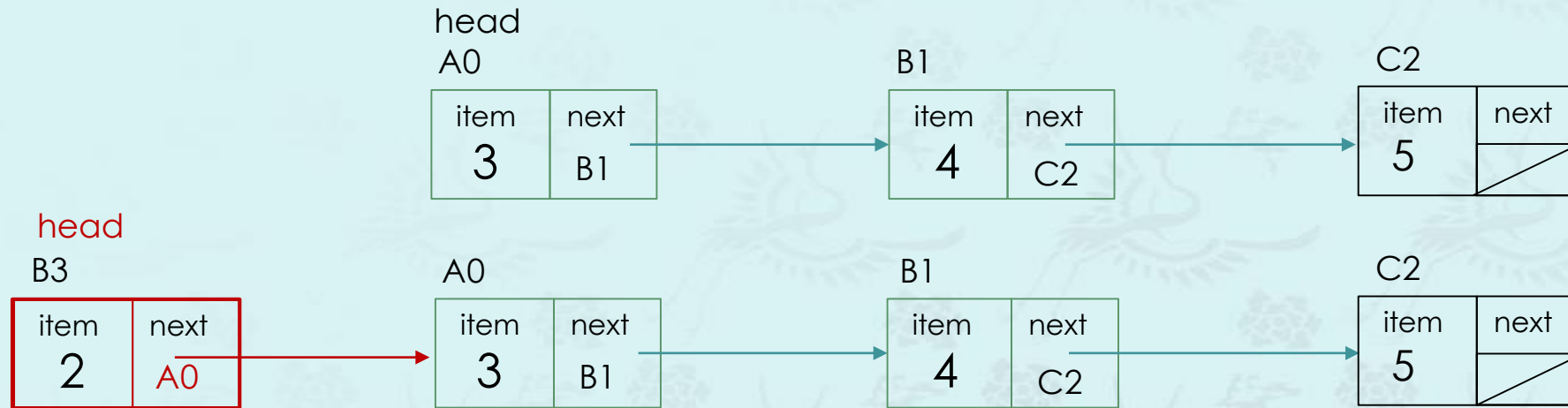


## Push a node: Three different cases

Given: an item(4) to insert – What was the most difficult part of this coding?

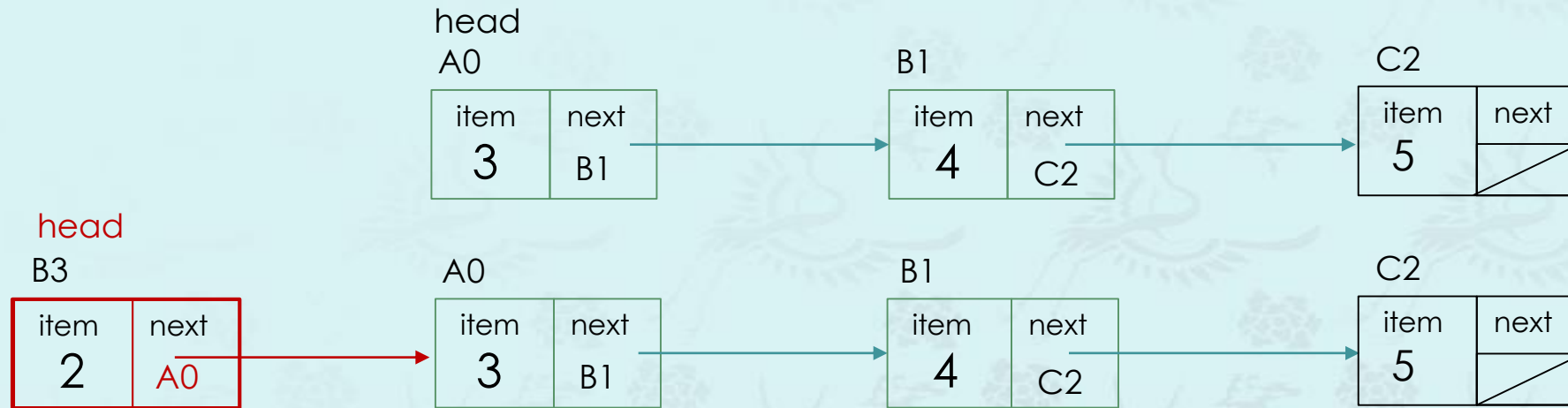


## push a node – Case 1; insert in front, head given



```
pNode node = new Node{2};  
node->next = head;  
head = node;
```

## push a node – Case 1; insert in front, head given

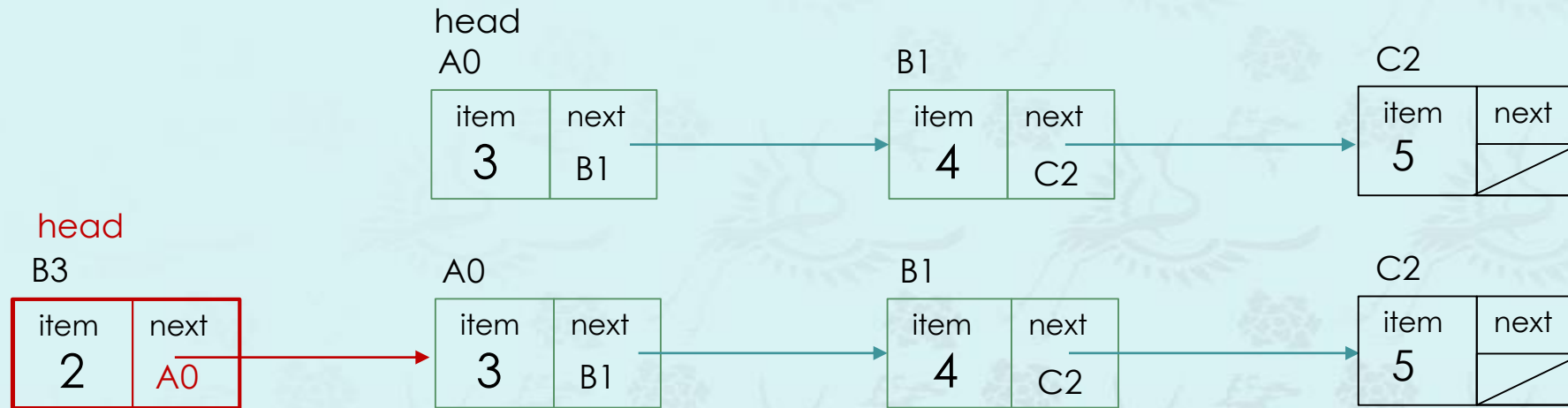


```
pNode node = new Node{2};  
node->next = head;  
head = node;
```

```
pNode node = new Node{2, nullptr, head};  
head = node;
```

```
struct Node{  
    int item;  
    pNode prev;  
    pNode next;  
    // constructor  
    Node(const int d=0, pNode p=nullptr, pNode n=nullptr){  
        item = d;        prev = p; next = n;  
    }  
    // destructor  
    ~Node() {}  
} Node;
```

## push a node – Case 1; insert in front, head given



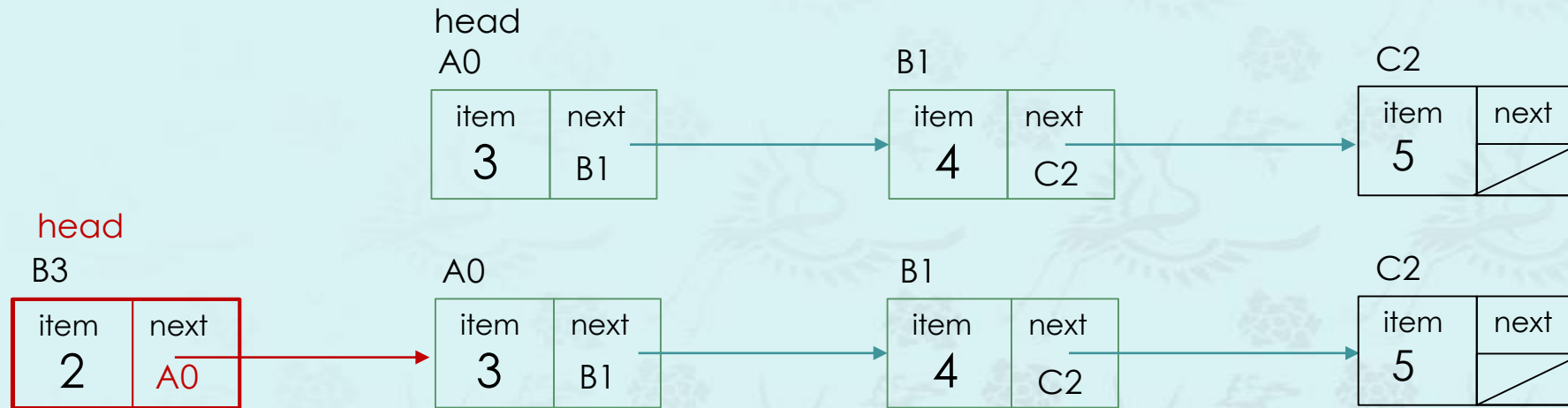
```
pNode node = new Node{2};  
node->next = head;  
head = node;
```

```
pNode node = new Node{2, nullptr, head};  
head = node;
```

```
void push_front(pList p, int val) {  
      
}  
}
```

Complete push\_front()

## push a node – Case 1; insert in front, head given

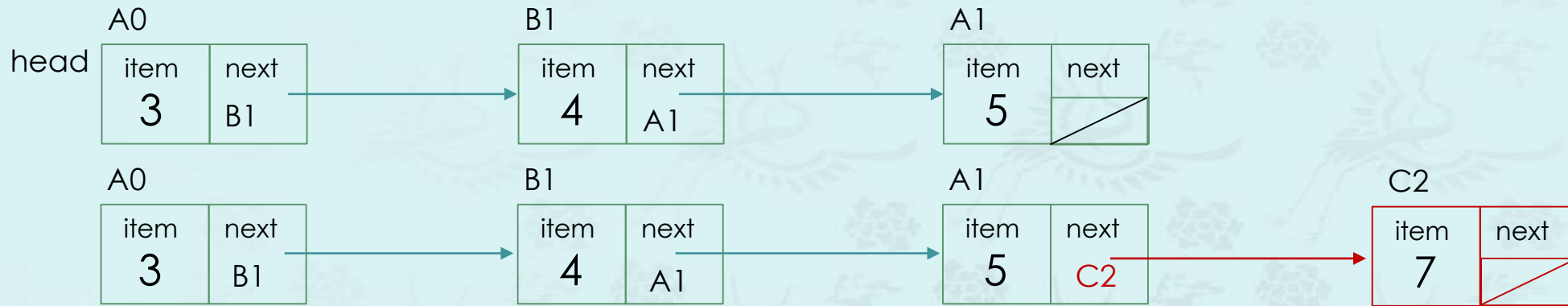


```
pNode node = new Node{2};  
node->next = head;  
head = node;
```

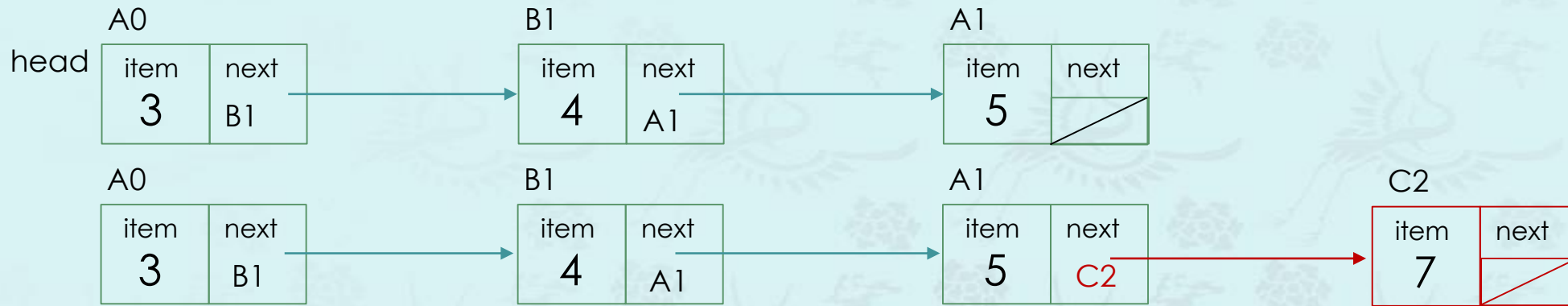
```
pNode node = new Node{2, nullptr, head};  
head = node;
```

```
void push_front(pList p, int val) {  
    p->head = new Node{val, nullptr, p->head};  
}
```

## push a node – Case 3; insert at end, head given

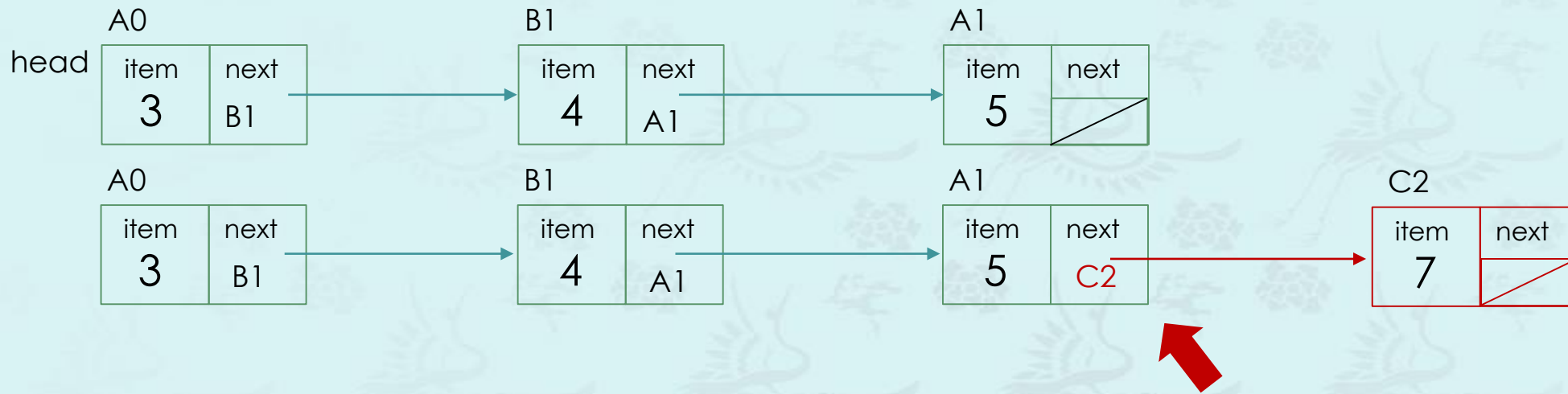


## push a node – Case 3; insert at end, head given



- find the last node.
- append a new Node{7}.

## push a node – Case 3; insert at end, head given



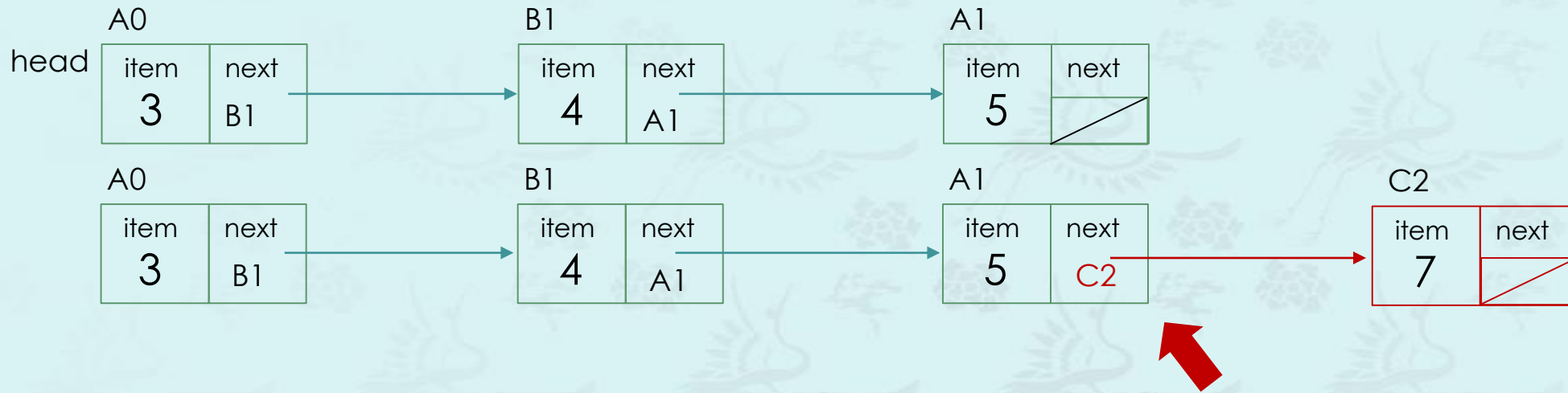
- find the last node.
- append a new Node{7}.

```
pNode last(pNode hp)
```

```
pNode x = hp;  
while  
    x = x->next;  
return x;
```



## push a node – Case 3; insert at end, head given



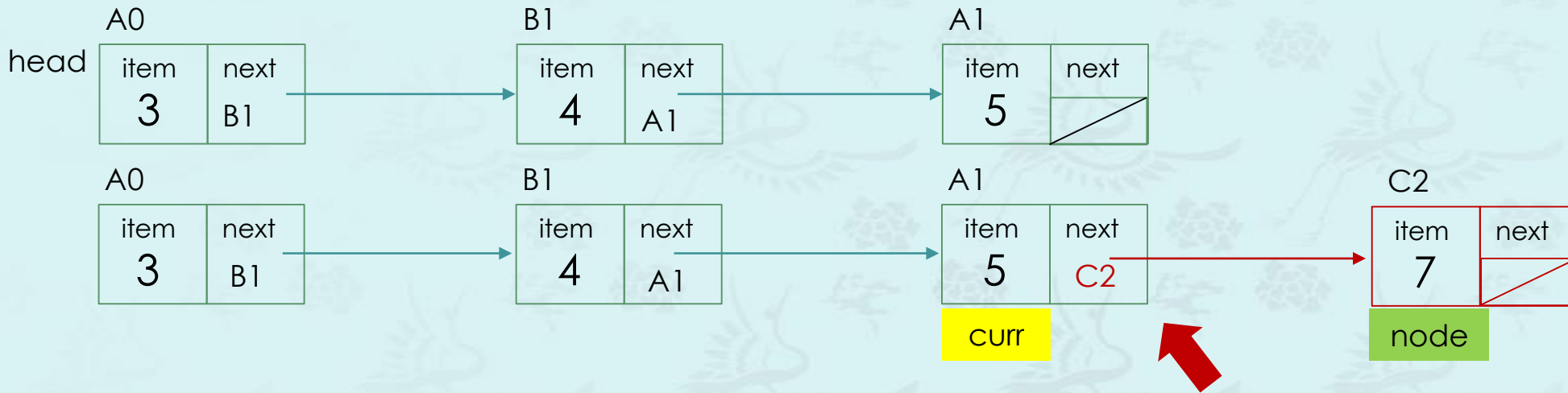
- find the last node.
- append a new Node{7}.

```
pNode last(pNode hp)
```

```
pNode x = hp;           ← need this or not?  
while (x->next != nullptr)  
    x = x->next;  
return x;
```

```
while (hp->next != nullptr)  
    hp = hp->next;  
return hp;
```

## push a node – Case 3; insert at end, head given



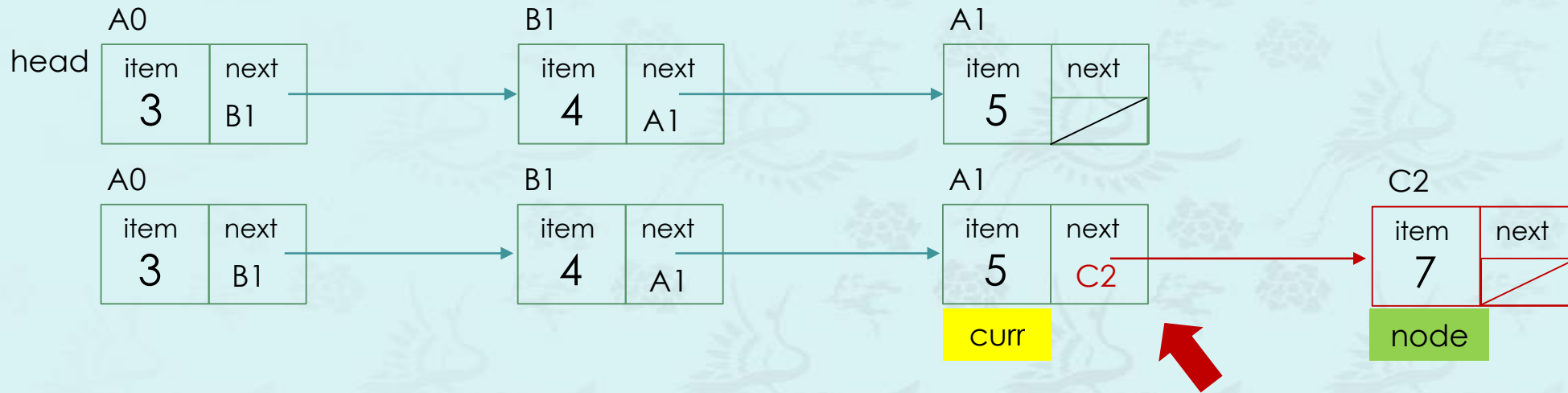
```
curr = last(list->head);  
pNode node = new Node{7};  
curr->next = node;
```

- find the last node.
- append a new Node{7}.

```
pNode last(pNode hp)
```

```
while (hp->next != nullptr)  
    hp = hp->next;  
return hp;
```

## push a node – Case 3; insert at end, head given



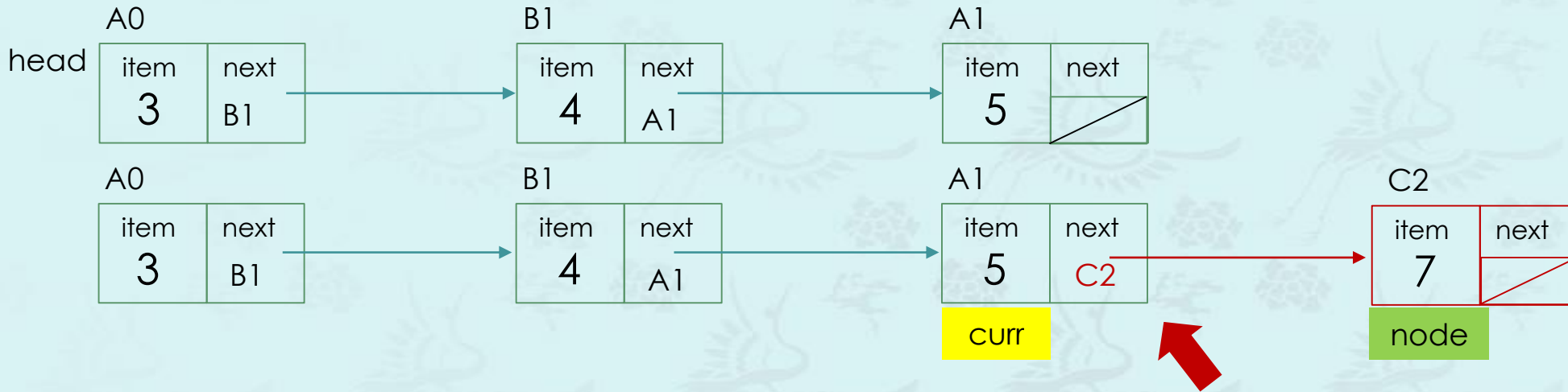
```
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pNode node = new Node{7};  
curr->next = node;
```

```
curr = last(list->head);  
curr->next = new Node{7};
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- find the last node.
- append a new Node{7}.

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

## push a node – Case 3; insert at end, head given



```
curr = last(list->head);  
pNode node = new Node{7};  
curr->next = node;
```

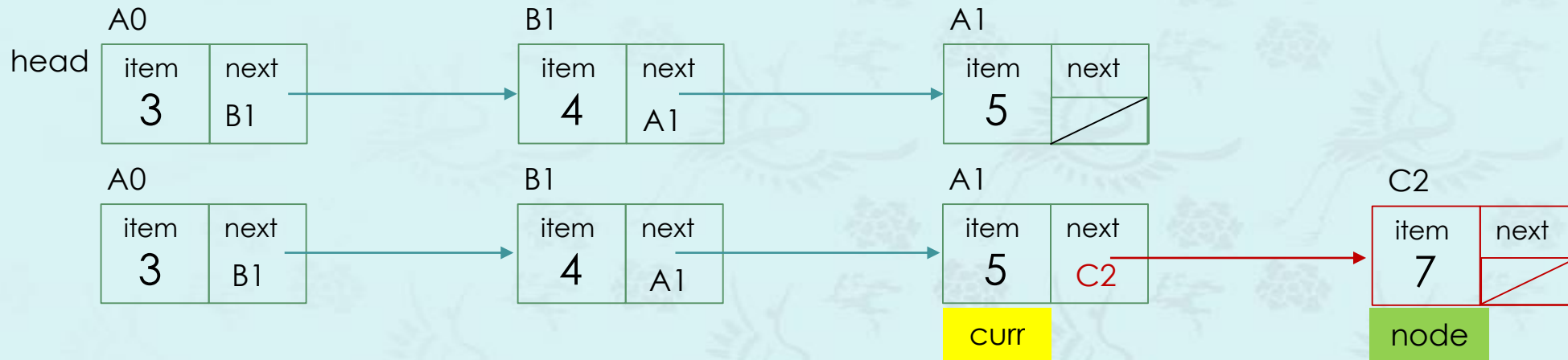
```
curr = last(list->head);  
curr->next = new Node{7};
```

```
void push_back(pList p, int val) {  
    curr = last(p->head);  
    curr->next = new Node{val};  
}
```

- find the last node.
- append a new Node{7}.

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

## push a node – Case 3; insert at end, head given

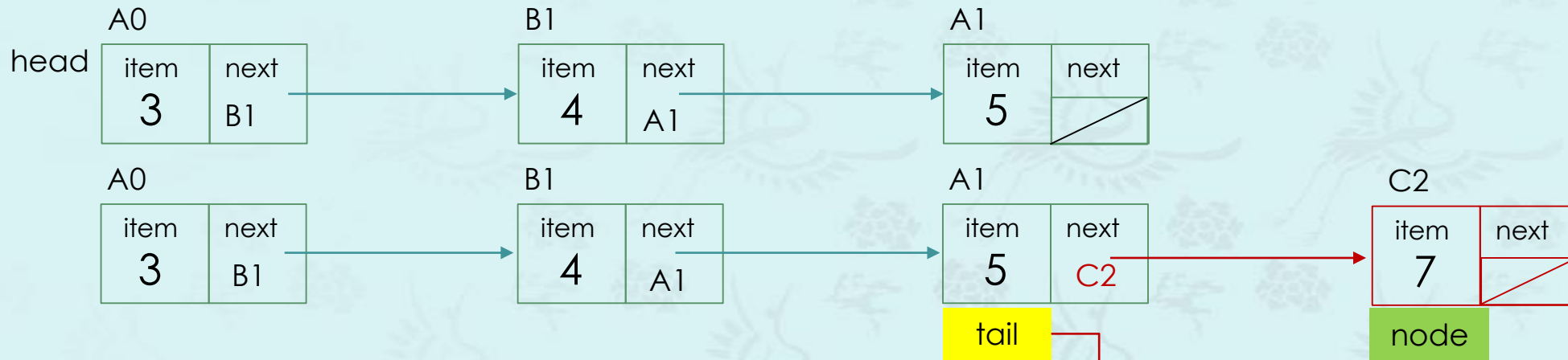


```
curr = last(list->head);  
pNode node = new Node{7};  
curr->next = node;
```

```
curr = last(list->head);  
curr->next = new Node{7};
```

```
void push_back(pList p, int val) { ← O(n)  
    curr = last(p->head);  
    curr->next = new Node{val};  
}
```

## push a node – Case 3; insert at end, head given



```
curr = last(list->head);  
pNode node = new Node{7};  
curr->next = node;
```

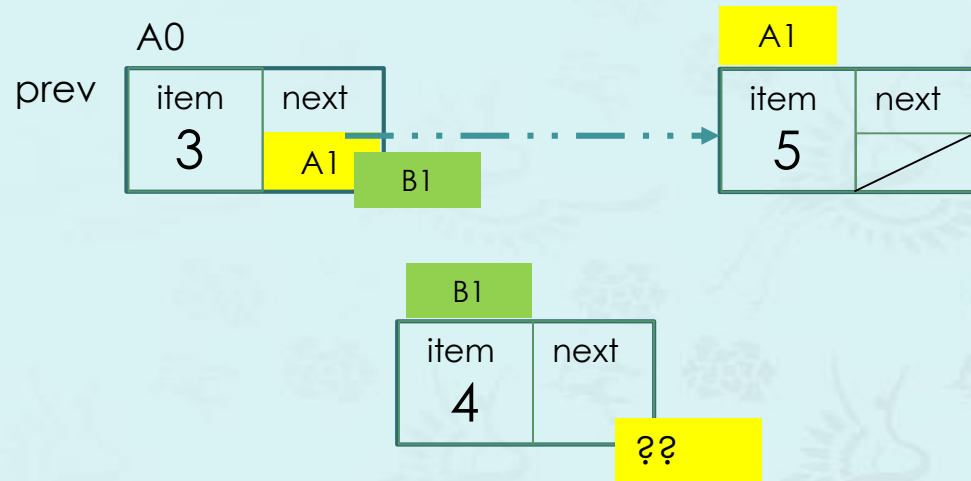
```
curr = last(list->head);  
curr->next = new Node{7};
```

```
void push_back(pList p, int val) { ← O(n)  
    curr = last(p->head);  
    curr->next = new Node{val};  
}
```

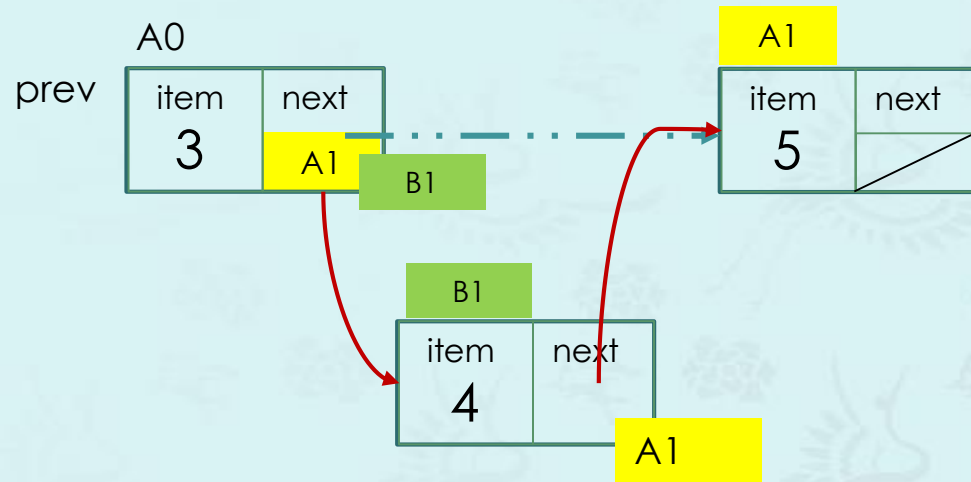
Using tail, rewrite push\_back() such that its time complexity is  $O(1)$ .

```
void push_back(pList p, int val) {  
    // ...  
}
```

## push a node – Case 2; insert in middle, prev given

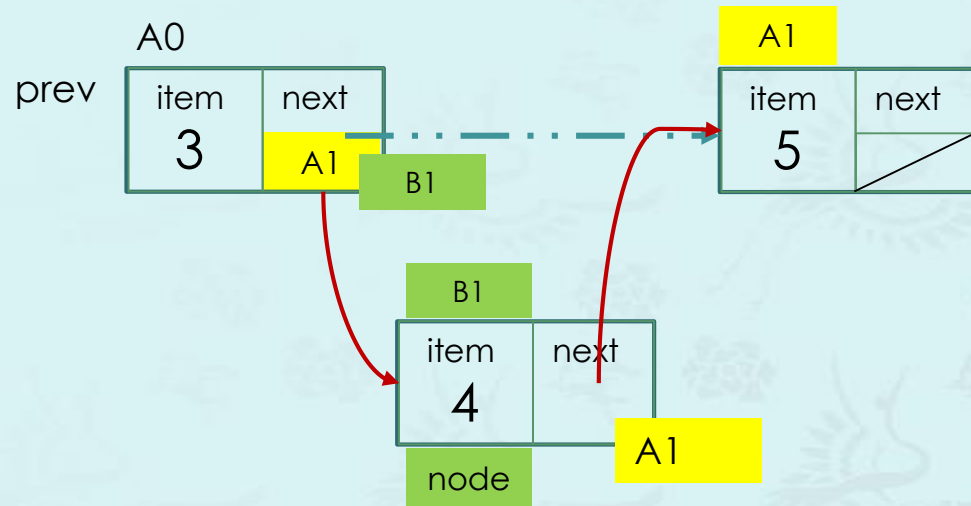


## push a node – Case 2; insert in middle, prev given





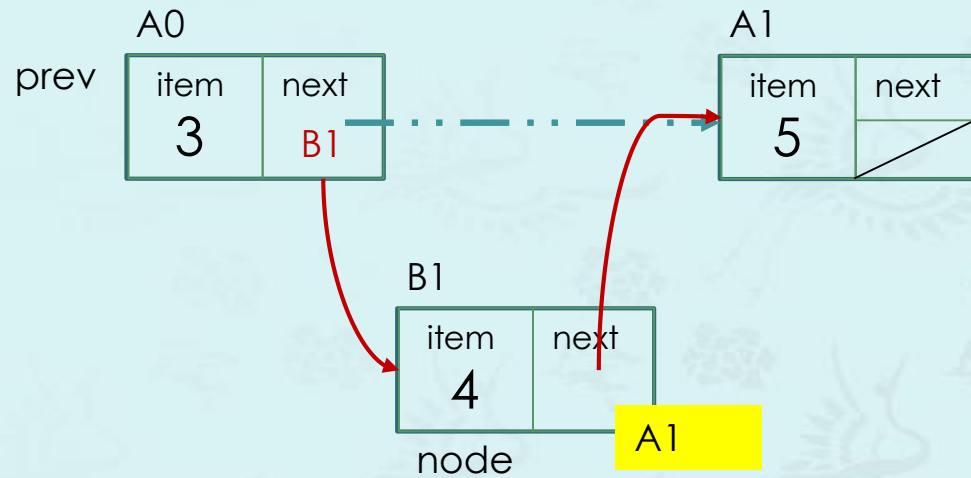
## push a node – Case 2; insert in middle, prev given



```
pNode node = new Node{4};  
prev->next = node;  
node->next = prev->next;
```

- There is a bug. Debug it!

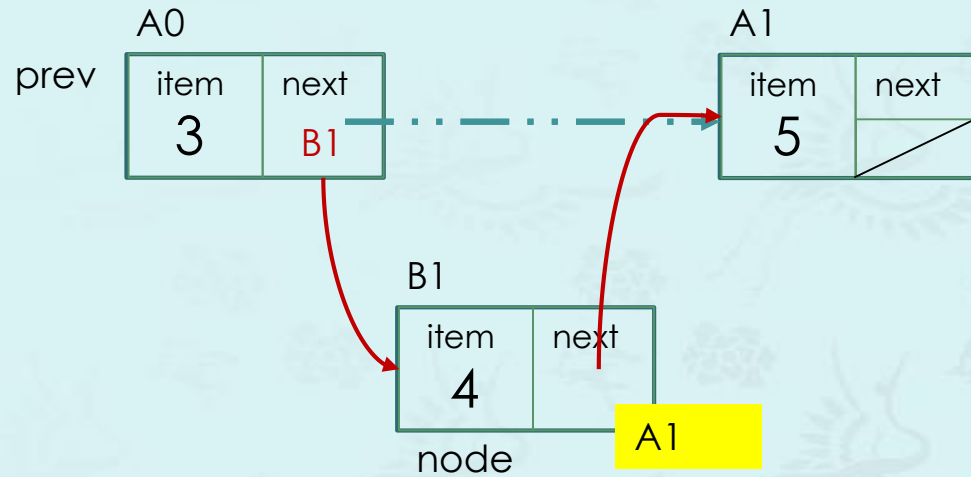
## push a node – Case 2; insert in middle, prev given



```
pNode node = new Node{4};  
prev->next = node; ❌ B1  
node->next = prev->next; A1
```

```
pNode node = new Node{4};  
node->next = prev->next; A1  
prev->next = node; B1
```

## push a node – Case 2; insert in middle, prev given

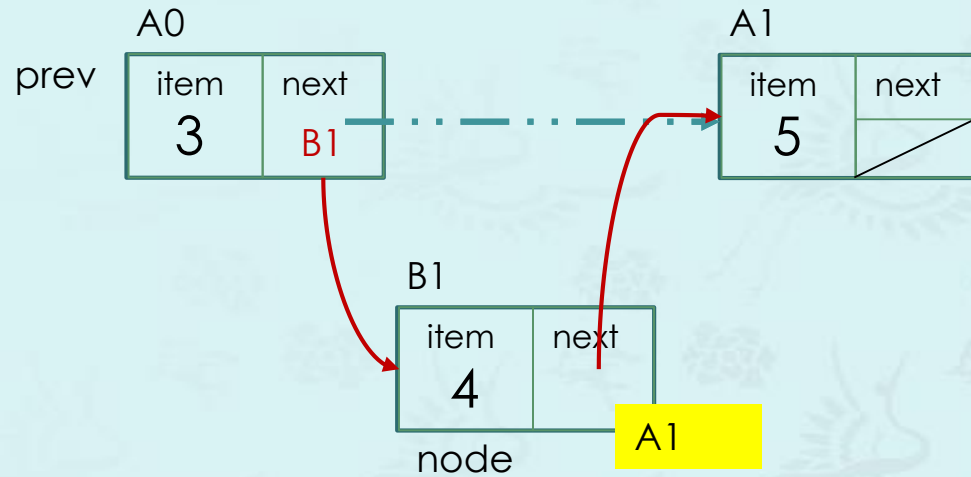


```
pNode node = new Node{4};  
prev->next = node; ❌ B1  
node->next = prev->next; A1
```

```
pNode node = new Node{4};  
node->next = prev->next; A1  
prev->next = node; B1
```

Can we do it in one line?

## push a node – Case 2; insert in middle, prev given



```
pNode node = new Node{4};  
prev->next = node; ❌  
node->next = prev->next;
```

B1
A1

```
pNode node = new Node{4};  
node->next = prev->next;  
prev->next = node;
```

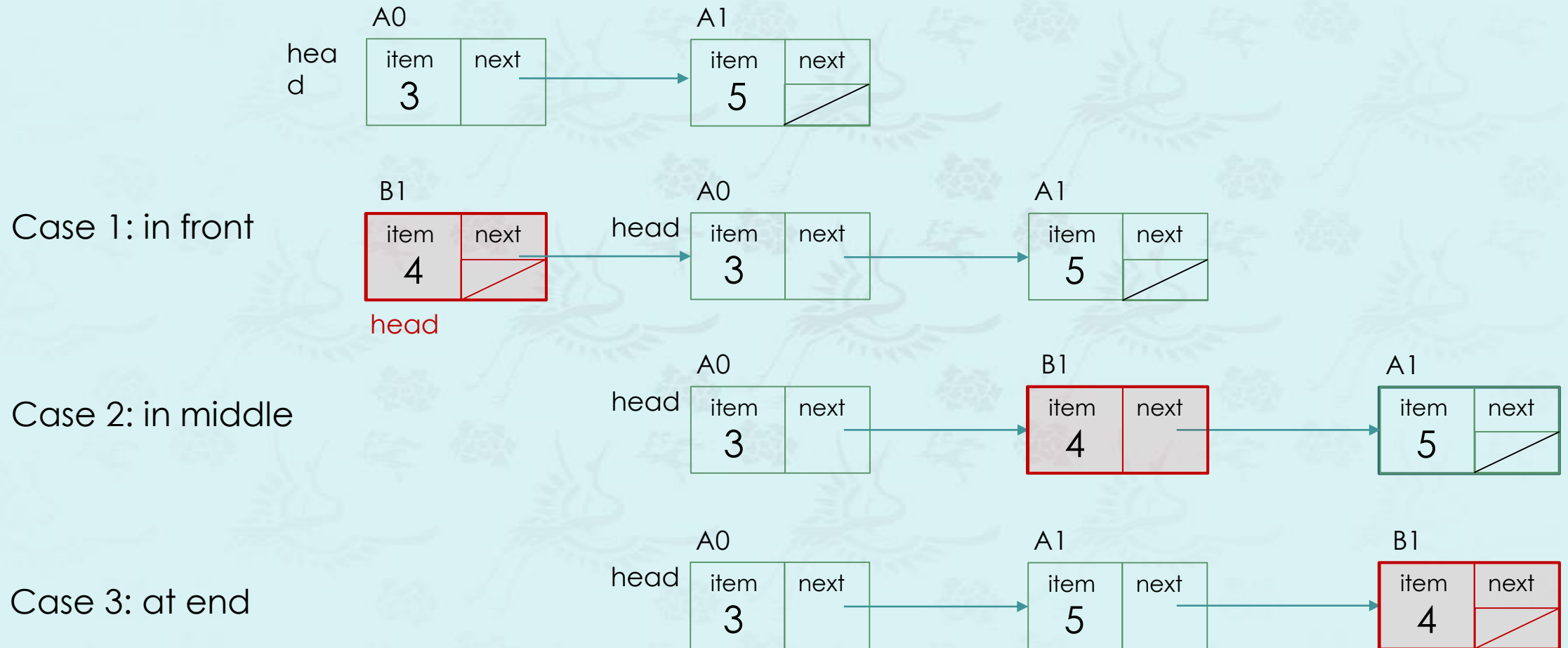
A1
B1

Can we do it in one line?

```
 = new Node(4, , );
```

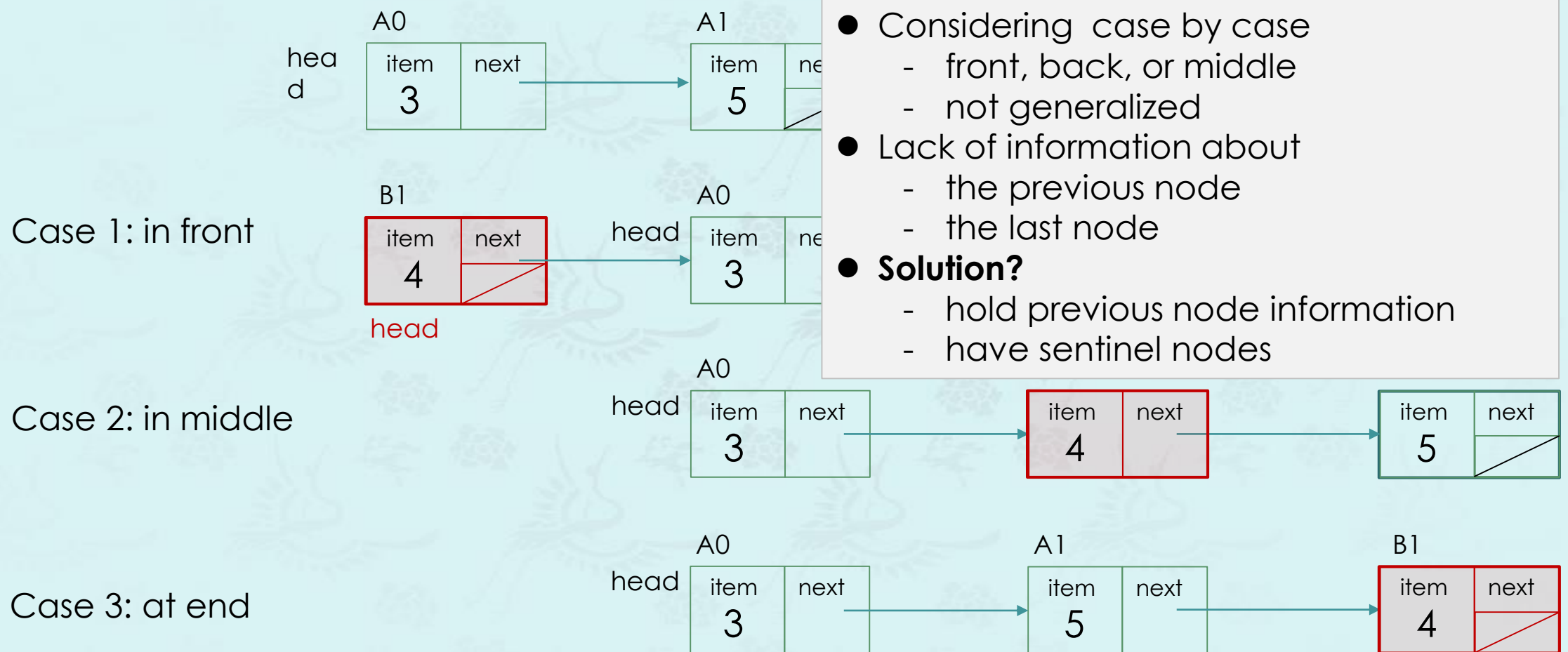
## Push a node: Three different cases

Given: an item(4) to insert – **What was the most difficult part of this coding?**

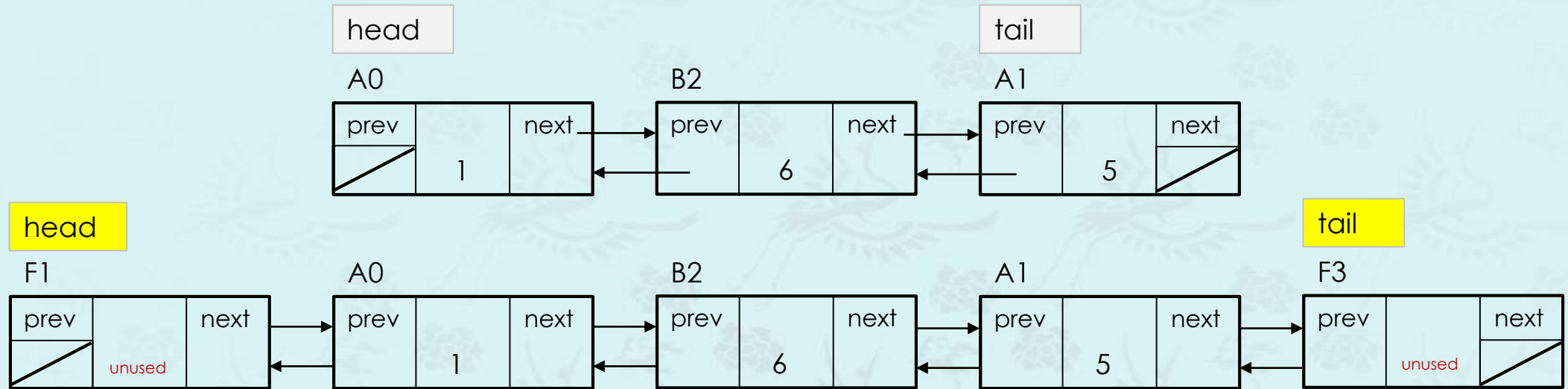


## Push a node: Three different cases

Given: an item(4) to insert – **What was the most difficult part of this coding?**



## doubly linked list with sentinel nodes



- **Solution**

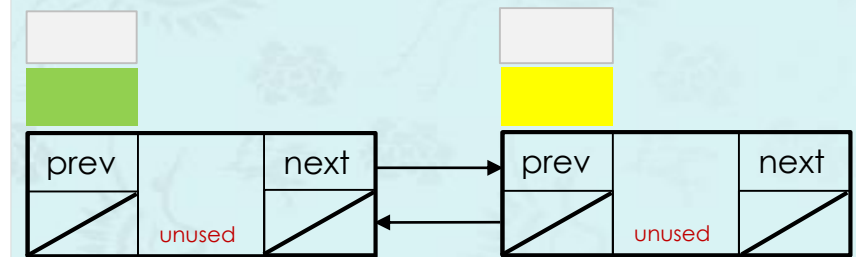
- **doubly linked list with sentinel nodes**
- Each node carries the pointer to the previous node.
- There is only one case (middle) with two sentinel nodes.

# doubly linked list with sentinel nodes

```
struct Node {  
    int    item;  
    Node*  prev;  
    Node*  next;  
    Node(const int d = 0, Node* p = nullptr, Node* x = nullptr) {  
        item = d; prev = p; next = x;  
    }  
    ~Node() {}  
};
```

```
struct List {  
    Node* head; //sentinel  
    Node* tail; //sentinel  
    int    size; //size of list, optional  
    List() {  
          
    }  
    ~List() {}  
};
```

```
using pNode = Node*;  
using pList = List*;
```



An **empty** doubly-linked list with sentinel nodes



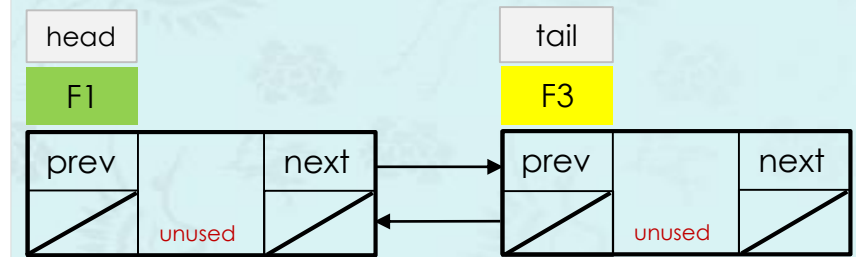
# doubly linked list with sentinel nodes

```
struct Node {
    int    item;
    Node*  prev;
    Node*  next;
    Node(const int d = 0, Node* p = nullptr, Node* x = nullptr) {
        item = d; prev = p; next = x;
    }
    ~Node() {}
};
```

```
struct List {
    Node* head; //sentinel
    Node* tail; //sentinel
    int    size; //size of list, optional
    List() { head = new Node{};    tail = new Node{};

    }
    ~List() {}
};
```

```
using pNode = Node*;
using pList = List*;
```



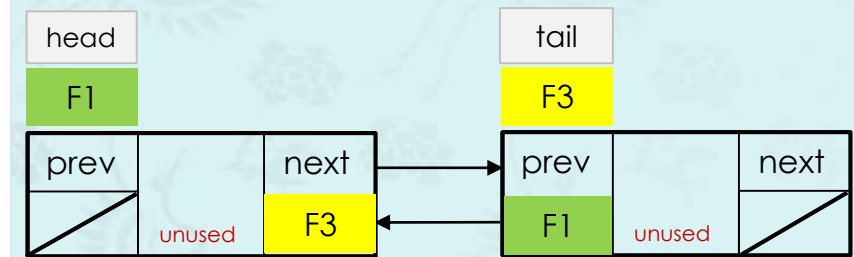
An **empty** doubly-linked list with sentinel nodes

# doubly linked list with sentinel nodes

```
struct Node {  
    int    item;  
    Node*  prev;  
    Node*  next;  
    Node(const int d = 0, Node* p = nullptr, Node* x = nullptr) {  
        item = d; prev = p; next = x;  
    }  
    ~Node() {}  
};
```

```
struct List {  
    Node* head; //sentinel  
    Node* tail; //sentinel  
    int    size; //size of list, optional  
    List() { head = new Node{};    tail = new Node{};  
            head->next = tail;    tail->prev = head;  
    }  
    ~List() {}  
};
```

```
using pNode = Node*;  
using pList = List*;
```



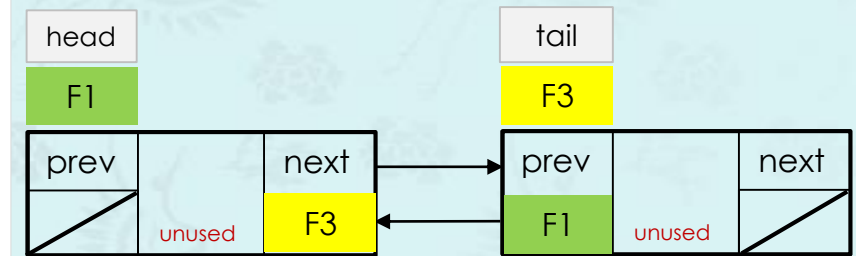
An **empty** doubly-linked list with sentinel nodes

# doubly linked list with sentinel nodes

```
struct Node {  
    int    item;  
    Node*  prev;  
    Node*  next;  
    Node(const int d = 0, Node* p = nullptr, Node* x = nullptr) {  
        item = d; prev = p; next = x;  
    }  
    ~Node() {}  
};
```

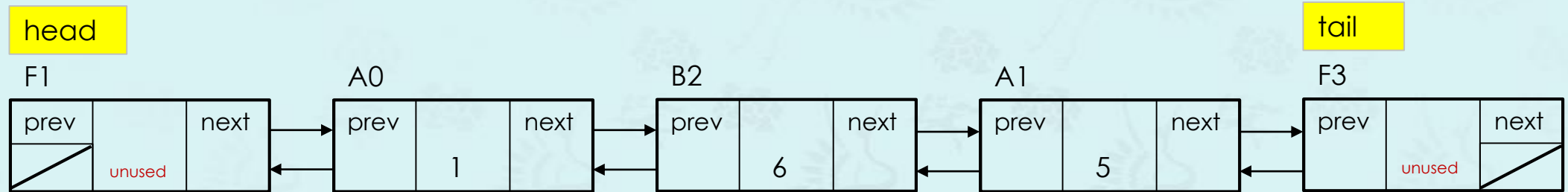
```
struct List {  
    Node* head; //sentinel  
    Node* tail; //sentinel  
    int    size; //size of list, optional  
    List() { head = new Node{};    tail = new Node{};  
            head->next = tail;    tail->prev = head;  
            size = 0;  
    }  
    ~List() {}  
};
```

```
using pNode = Node*;  
using pList = List*;
```



An **empty** doubly-linked list with sentinel nodes

## doubly linked list with sentinel nodes



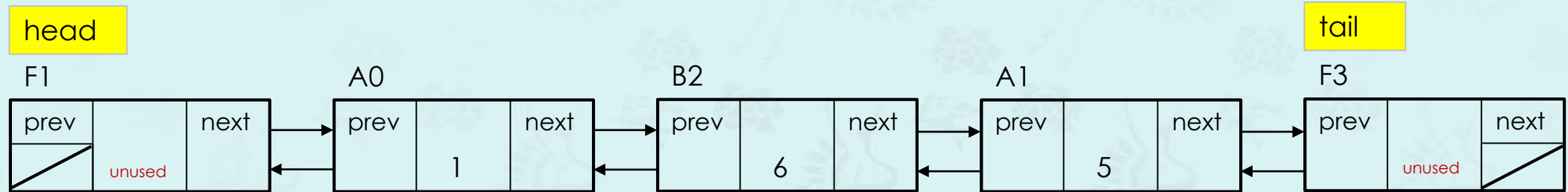
```
pNode  (pList p) {  
    return p->head->next;  
}
```

← What is the name of this function?

```
pNode  (pList p) {  
    return p->tail;  
}
```

← What is the name of this function?

## doubly linked list with sentinel nodes - **Exercise**

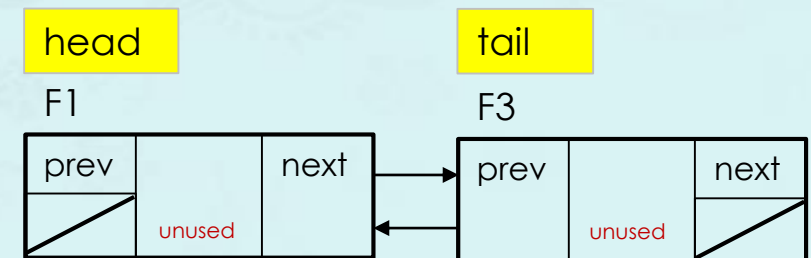


```
pNode begin(pList p) {  
    return p->head->next;  
}
```

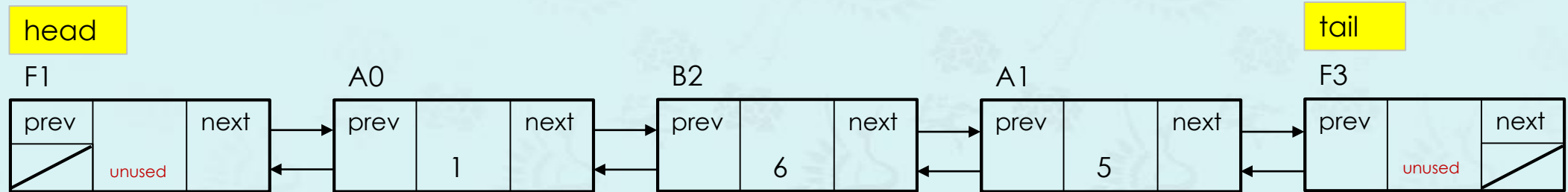
```
bool  (pList p) {  
    return begin(p) == end(p);  
}
```

```
pNode end(pList p) {  
    return p->tail;  
}
```

```
pNode  (pList p) {  
    return end(p)->prev;  
}
```



## doubly linked list with sentinel nodes - **Exercise**

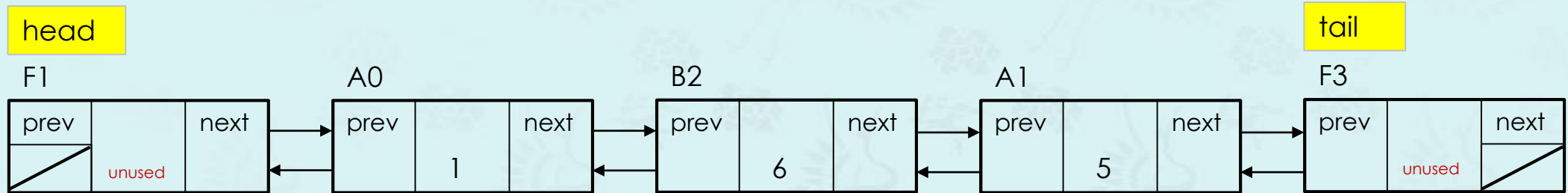


```
pNode begin(pList p) {  
    return p->head->next;  
}
```

```
pNode end(pList p) {  
    return p->tail;  
}
```

```
int  (pList p) {  
    int count = 0;  
    pNode c = begin(p);  
    while(c != end(p)) {  
        count++;  
        c = c->next;  
    }  
    return count;  
}
```

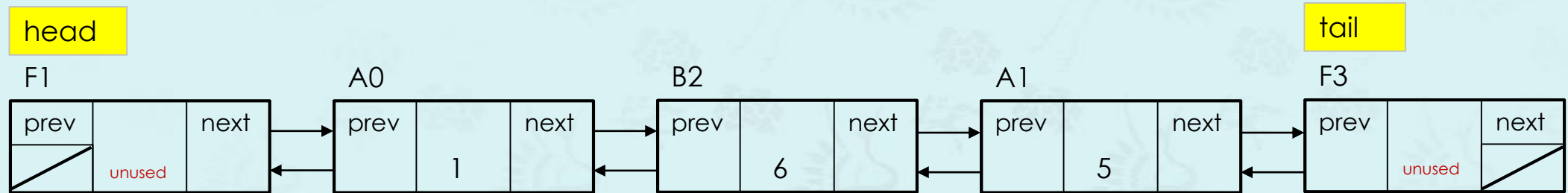
## doubly linked list with sentinel nodes - **Exercise**



```
int size(pList p) {  
    int count = 0;  
      
    return count;  
}
```

```
int size(pList p) {  
    int count = 0;  
    pNode c = begin(p);  
    while(c != end(p)) {  
        count++;  
        c = c->next;  
    }  
    return count;  
}
```

## doubly linked list with sentinel nodes - **Exercise**

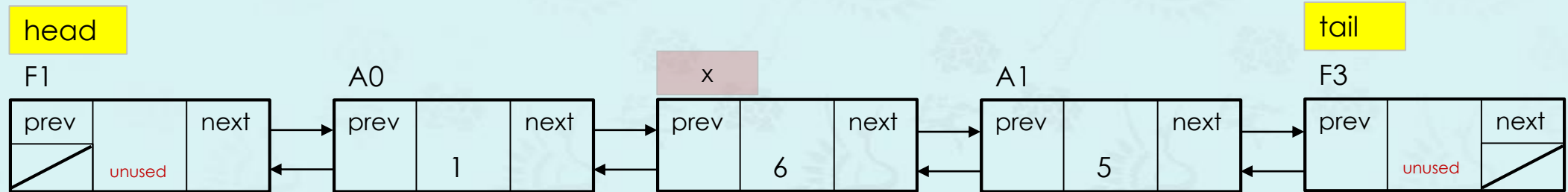


```
int size(pList p) {  
    int count = 0;  
    for (pNode c = begin(p); c != end(p); c = c->next)  
        count++;  
    return count;  
}
```

```
int size(pList p) {  
    int count = 0;  
    pNode c = begin(p);  
    while(c != end(p)) {  
        count++;  
        c = c->next;  
    }  
    return count;  
}
```

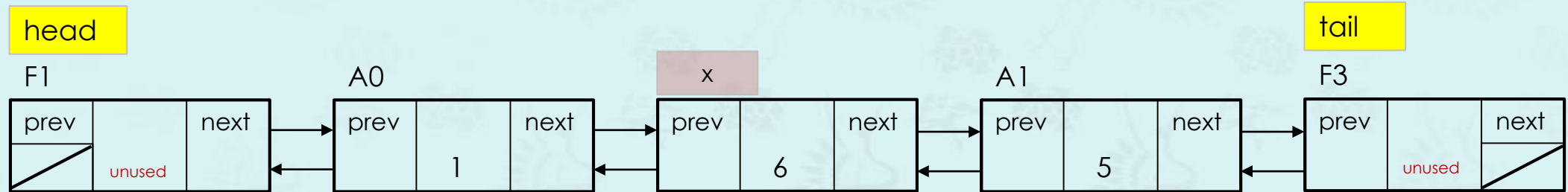


## doubly linked list with sentinel nodes



```
pNode (pList p, int val){  
    pNode curr = begin(p);  
    while(curr != end(p)) {  
        if (curr->item == val)  
            return curr;  
        curr = curr->next;  
    }  
    return curr;  
}
```

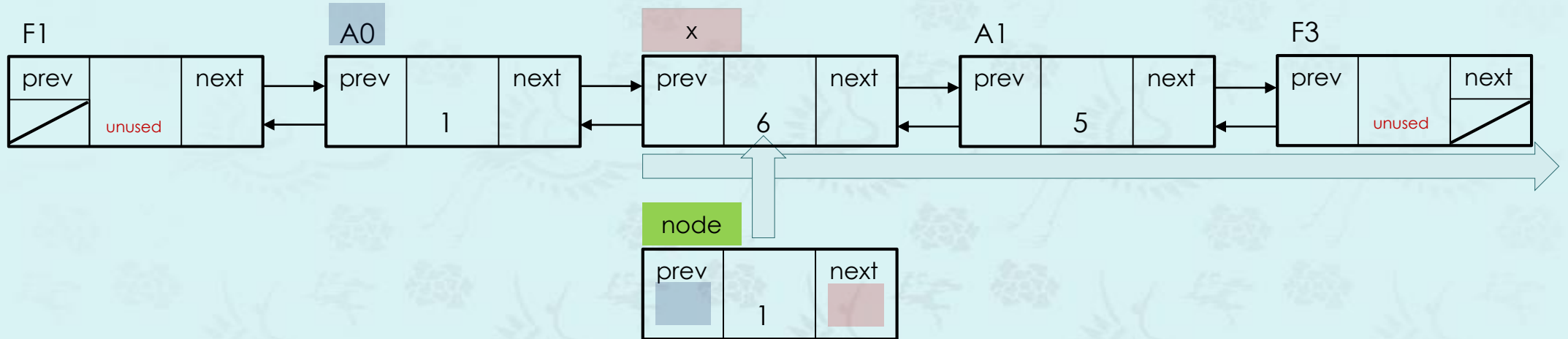
## doubly linked list with sentinel nodes



- (1) Rewrite this function using for loop.
- (2) What is the return value if not found?

```
pNode  (pList p, int val){  
    pNode curr = begin(p);  
    while(curr != end(p)) {  
        if (curr->item == val)  
            return curr;  
        curr = curr->next;  
    }  
    return curr;  
}
```

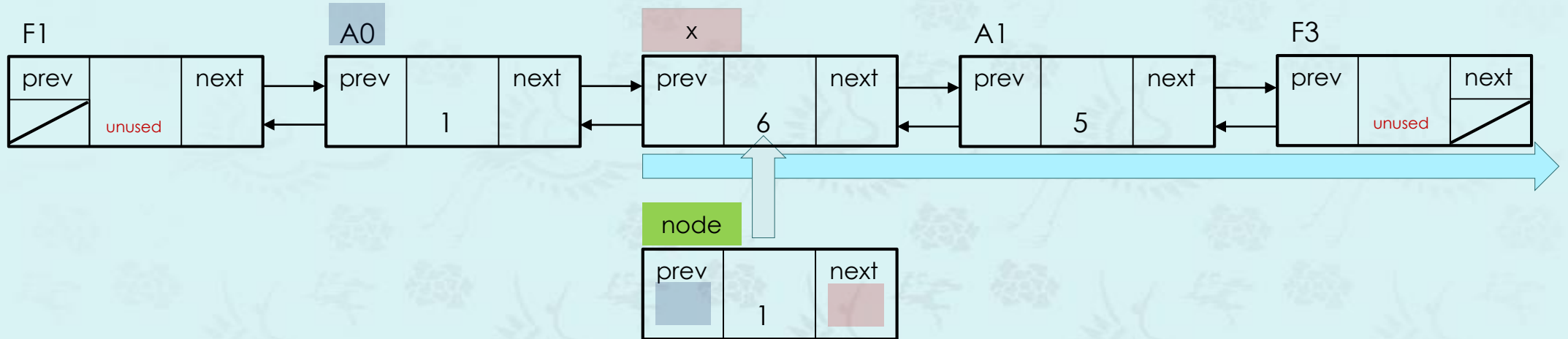
## doubly linked list with sentinel nodes – insert a node with val at the node x



```
void insert(pNode x, int val){  
  
  
  
  
  
  
}
```

```
struct Node{  
    int item;  
    Node* prev;  
    Node* next;  
    // constructor  
    Node(int d=0, Node* p=nullptr, Node* x=nullptr) {  
        item = d;          prev = p;  next = x;  
    }  
    // destructor  
    ~Node() {}  
};
```

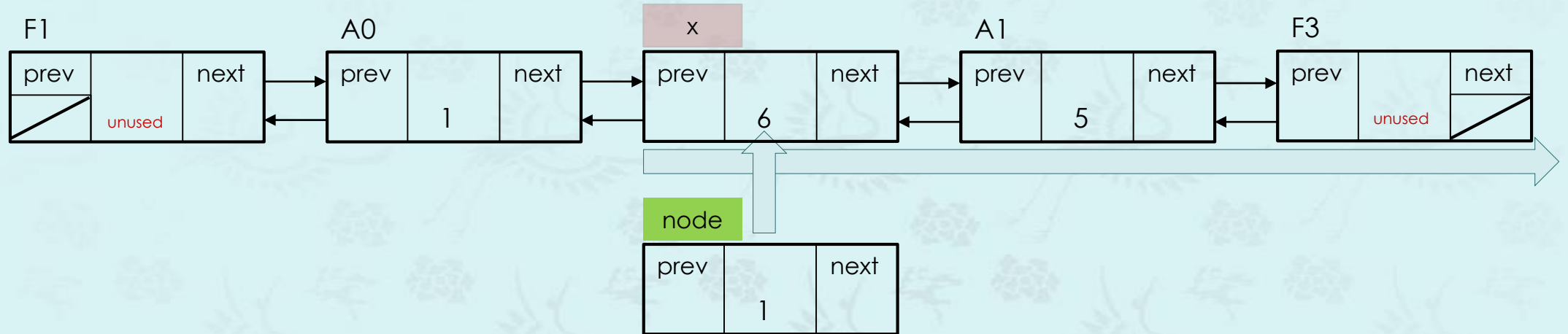
## doubly linked list with sentinel nodes – insert a node with val at the node x



```
void insert(pNode x, int val){  
    pNode node = new Node{ val, x->prev, x };  
  
}
```

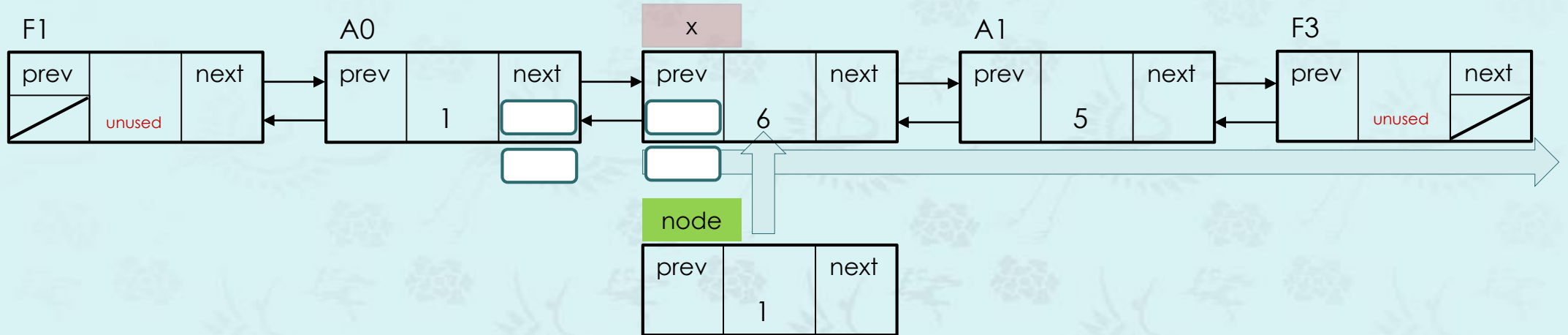
```
struct Node{  
    int item;  
    Node* prev;  
    Node* next;  
    // constructor  
    Node(int d=0, Node* p=nullptr, Node* x=nullptr) {  
        item = d;          prev = p;  next = x;  
    }  
    // destructor  
    ~Node() {}  
};
```

## doubly linked list with sentinel nodes – **insert a node with val at the node x**



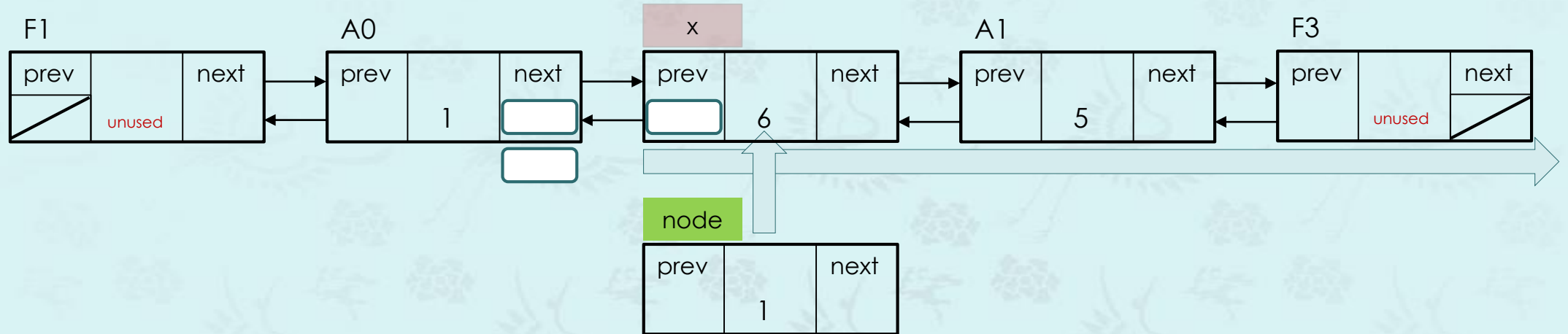
```
void insert(pNode x, int val){  
    pNode node = new Node{ val, x->prev, x };  
     = node;  
}
```

## doubly linked list with sentinel nodes – insert a node with val at the node x



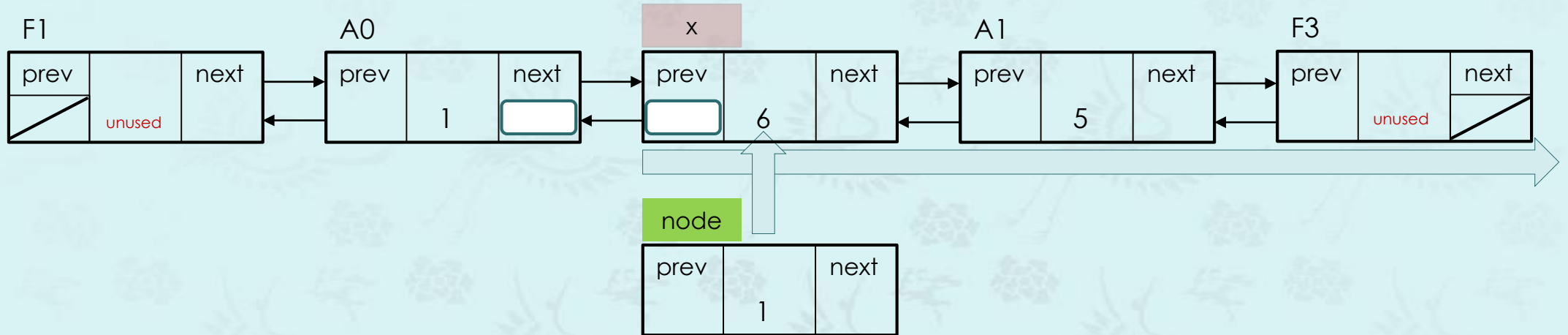
```
void insert(pNode x, int val){  
    pNode node = new Node{ val, x->prev, x };  
     = node;  
}
```

## doubly linked list with sentinel nodes – insert a node with val at the node x



```
void insert(pNode x, int val){  
    pNode node = new Node{ val, x->prev, x };  
    x->prev =  = node;  
}
```

## doubly linked list with sentinel nodes – insert a node with val at the node x



```
void insert(pNode x, int val){  
    pNode node = new Node{ val, x->prev, x };  
    x->prev = x->prev->next = node;  
}
```



## doubly linked list with sentinel nodes – **insert a node with val at the node x**



Case 1: in front

```
void push_front(pList p, int val){  
    insert(begin(p), val);  
}
```

Case 3: at end

```
void push_back(pList p, int val){  
    insert(end(p), val);  
}
```

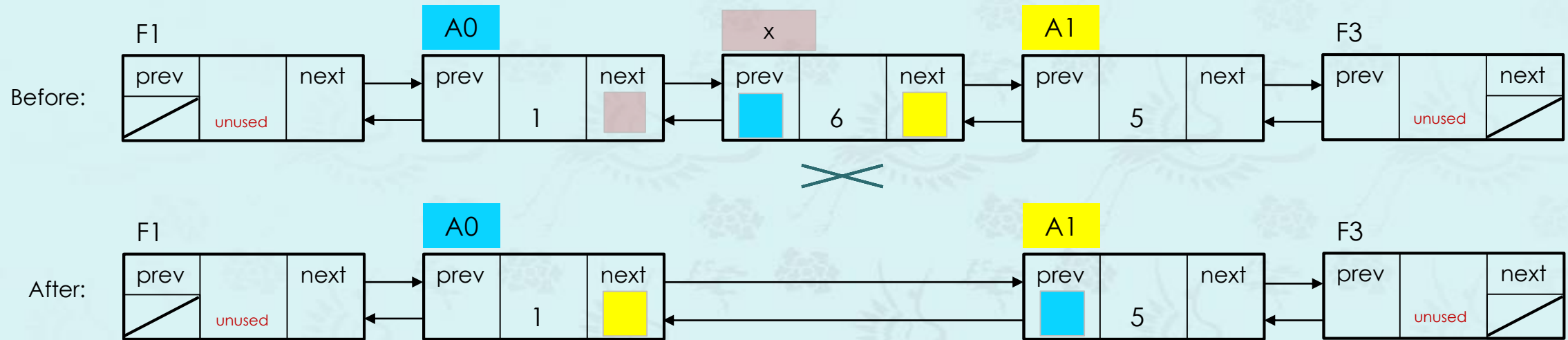
Case 2: in middle

```
void push(pList p, int val, int x){  
    insert(find(p, x), val);  
}
```

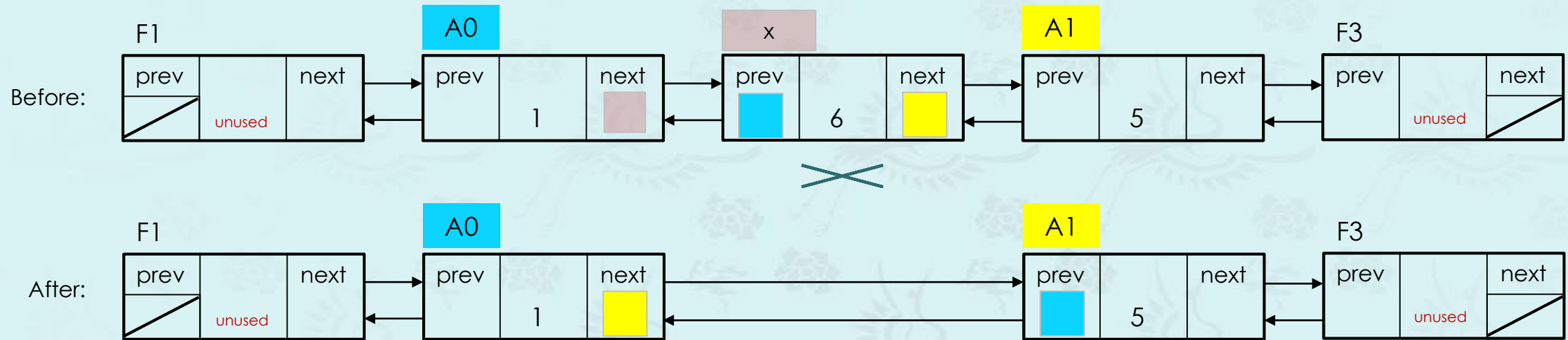
```
void insert(pNode x, int val){  
    pNode node = new Node{ val, x->prev, x };  
    x->prev = x->prev->next = node;  
}
```



## doubly linked list with sentinel nodes – **erase the node x**



## doubly linked list with sentinel nodes – **erase the node x**



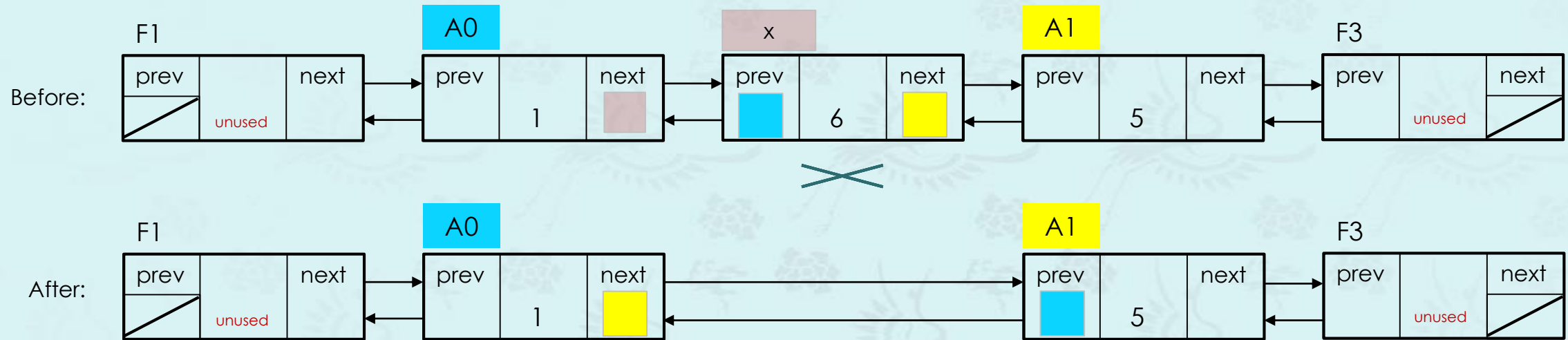
```
void erase(          ) {
```

```
                                                   
                                                 
```

```
    delete x;
```

```
}
```

## doubly linked list with sentinel nodes – **erase the node x**



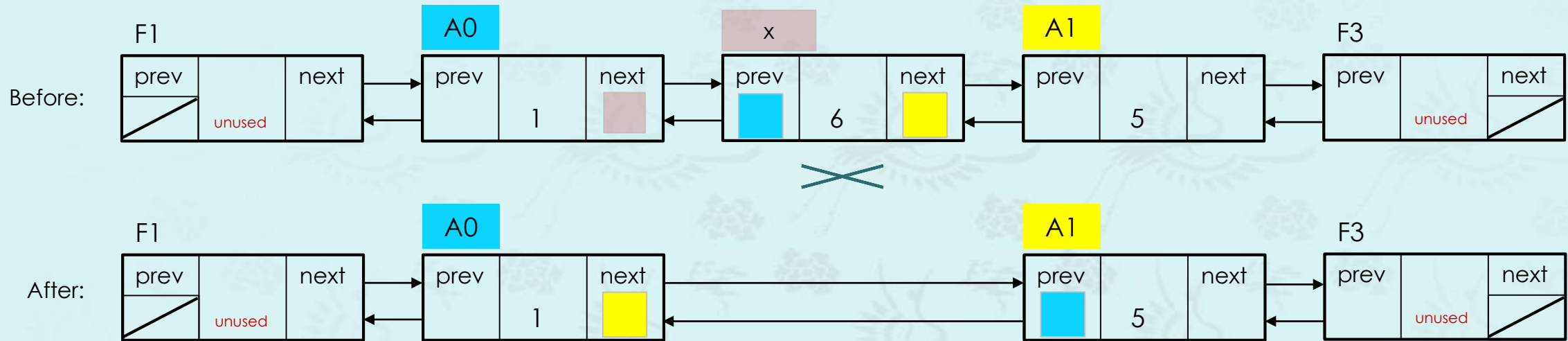
```
void erase(pNode x){
```



```
    delete x;
```

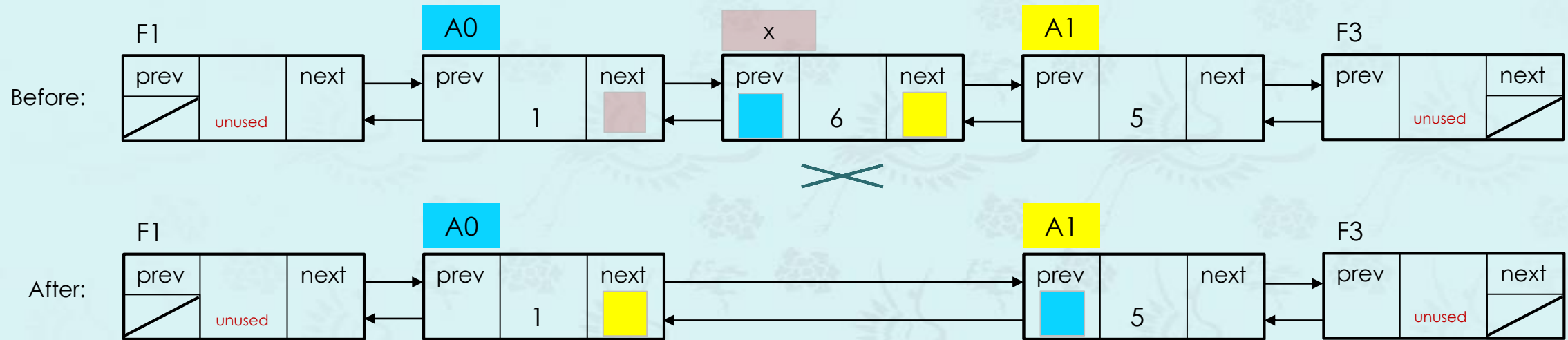
```
}
```

## doubly linked list with sentinel nodes – **erase the node x**



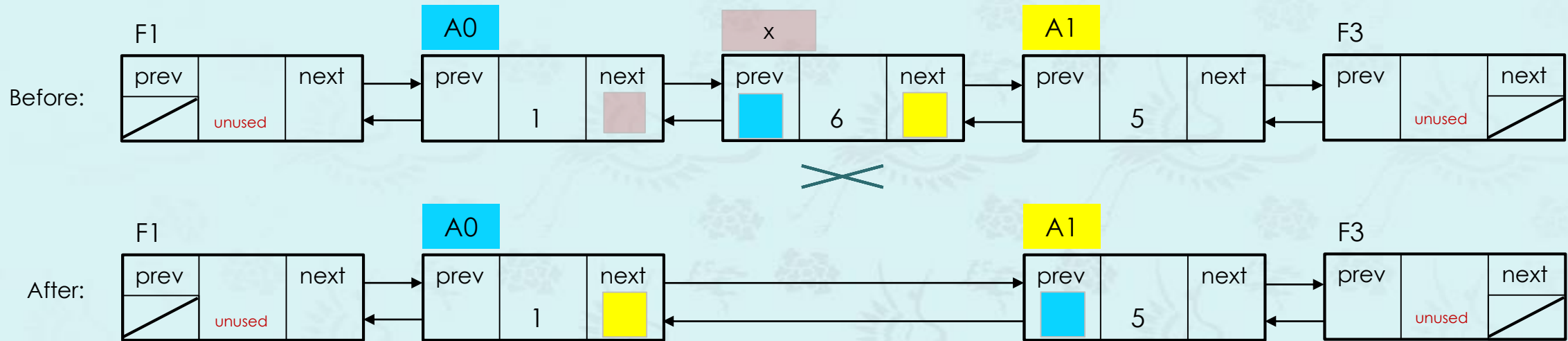
```
void erase(pNode x){  
    x->prev->next = x->next;  
    delete x;  
}
```

## doubly linked list with sentinel nodes – **erase the node x**



```
void erase(pNode x){  
    x->prev->next = x->next;  
    x->next->prev = x->prev;  
    delete x;  
}
```

## doubly linked list with sentinel nodes – **pop a node with val**



```
void erase(pNode x){  
    x->prev->next = x->next;  
    x->next->prev = x->prev;  
    delete x;  
}
```

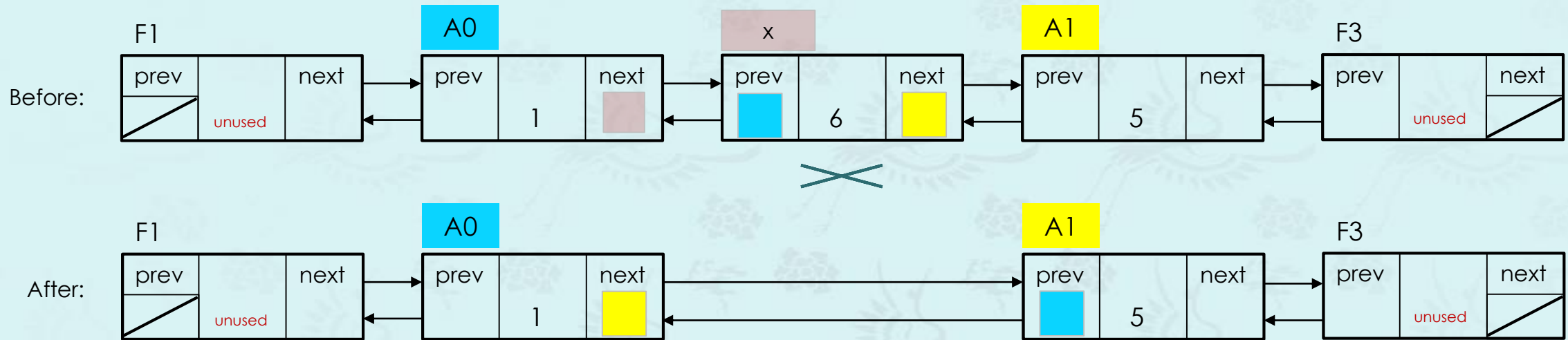
```
pNode find(pList p, int val)
```

Implement pop() using erase() and find().

```
void pop(pList p, int val){  
  
}
```



## doubly linked list with sentinel nodes – **pop a node with val**



```
void erase(pNode x){  
    x->prev->next = x->next;  
    x->next->prev = x->prev;  
    delete x;  
}
```

```
pNode find(pList p, int val)
```

Implement pop() using erase() and find().

```
void pop(pList p, int val){  
    erase(find(p, val));  
}
```

This code may not work some cases?  
How can you fix it?

pNode begin(pList p);	// returns the first node, not sentinel node
pNode end(pList p);	// returns the ending sentinel node
pNode half(pList p)	// returns the node in the middle of the list
pNode find(pList p, int val);	// returns the first node with val
void clear(pList p);	// free list of nodes
bool empty(pList p);	// true if empty, false if no empty
int size(pList p);	// returns size in the list
<b>void insert(pNode x, int val);</b>	// inserts a new node with val at the node x
<b>void erase(pNode x);</b>	// deletes a node and returns the previous node
void push(pList p, int val, int x);	// inserts a node with val at the node with x
void push_front(pList p, int val);	// inserts a node at front of the list
void push_back(pList p, int val);	// inserts a node with val at end of the list
void push_sorted(pList p, int val, bool ascending = true);	// inserts a node in sorted
void pop(pList p, int val);	// deletes the first node with val
void pop_front(pList p);	// deletes the first node in the list
void pop_back(pList p);	// deletes the last node in the list, O(1)
void pop_backN(pList p);	// deletes all the nodes O(n)
void pop_all(pList p, int val);	// deletes all the nodes with val
<b>pList</b> sort(pList p);	// returns a `new list` sorted
bool sorted(pList p);	// returns true if the list is sorted
void unique(pList p);	// returns list with no duplicates, sorted
void reverse(pList p);	// reverses the sequence
void shuffle(pList p);	// shuffles the list
void show(pList p);	// shows all items in linked list

---

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