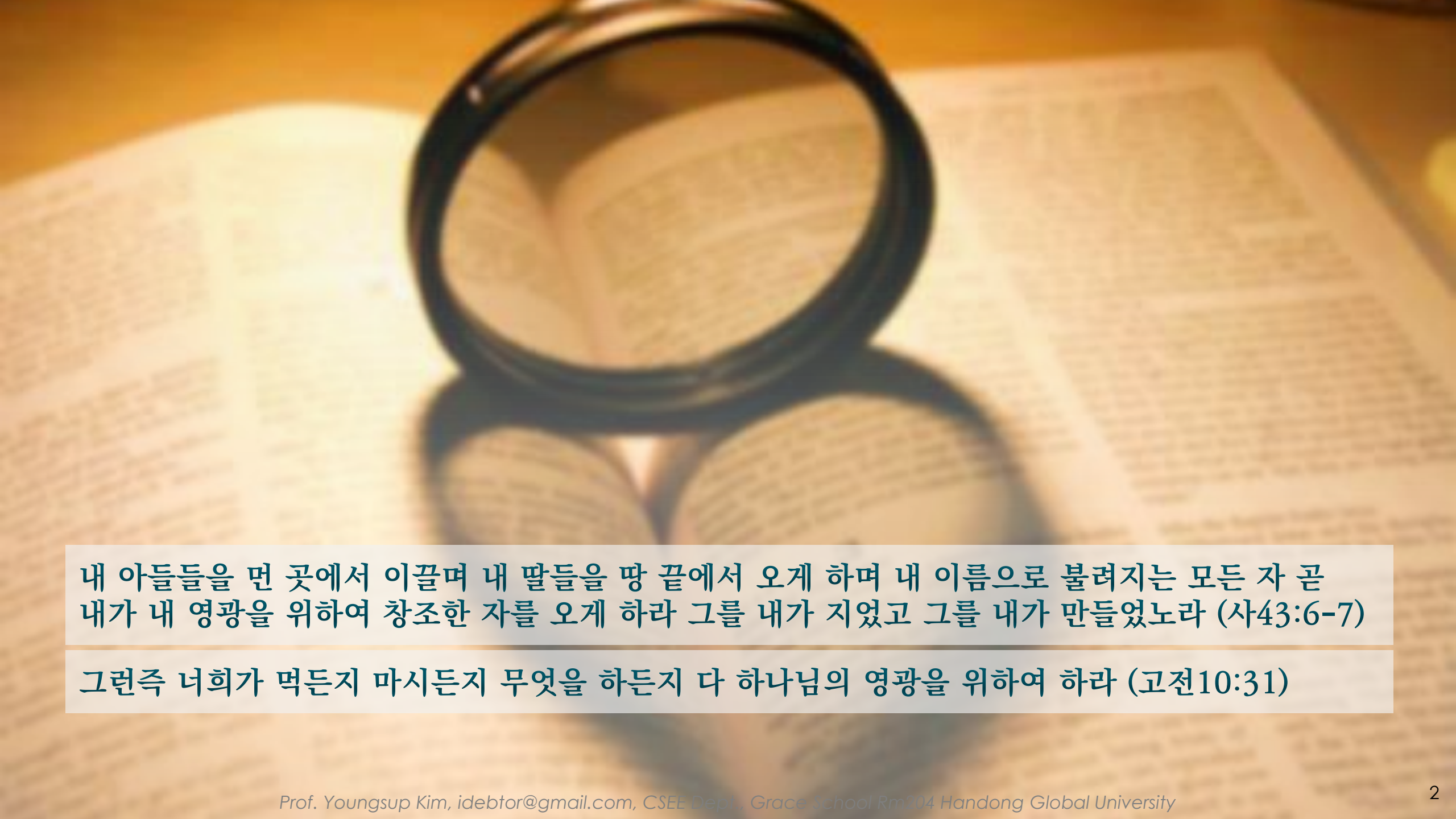




Data Structures

Chapter 4

1. Singly Linked List
 - Pointer Reviewed & Linked
 - Linked List (1)
 - **Linked List (2)**
2. Doubly Linked List

A pair of black-rimmed glasses is placed on an open book. The book's pages are yellowed with age and feature faint, illegible text. The scene is lit with a warm, golden light, creating a soft, contemplative atmosphere.

내 아들들을 먼 곳에서 이끌며 내 딸들을 땅 끝에서 오게 하며 내 이름으로 불려지는 모든 자 곧
내가 내 영광을 위하여 창조한 자를 오게 하라 그를 내가 지었고 그를 내가 만들었노라 (사43:6-7)

그런즉 너희가 먹든지 마시든지 무엇을 하든지 다 하나님의 영광을 위하여 하라 (고전10:31)

Self-Referenced Data Structures

```
class Node {  
public:  
    int    data;  
    Node* next;  
};
```



constructor, destructor

Self-Referenced Data Structures

```
class Node {  
public:  
    int    data;  
    Node* next;  
};
```

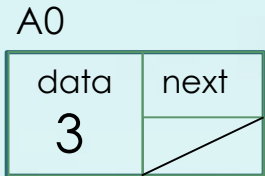
```
struct Node {  
    int    data;  
    Node* next;  
  
    Node(int i=0, Node* n=nullptr){  
        data = i, next = n;  
    }  
    ~Node() {};  
};  
  
int main( ) {  
    Node* head, *x, *y;  
    Node* p = new Node;  
    ...  
}
```

```
struct Node {  
    int    data;  
    Node* next;  
};  
using pNode Node*;  
  
int main() {  
    pNode head, x, y;  
    pNode p = new Node;  
    ...  
}
```

Yet another style of constructor: **"initializer"**

```
Node(int i, Node* n): data(i), next(n) {}
```

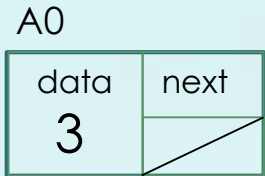
a new node instantiation



- (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    data;  
    Node*  prev; ← unused in  
    Node*  next; ← singly linked  
};  
  
struct List {  
    Node*  head;  
    Node*  tail;  
    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}

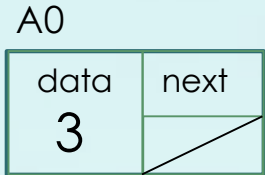
```
Node* n = new Node{3, nullptr, nullptr};
```

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

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

Any invalid initialization code?

a new node instantiation



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

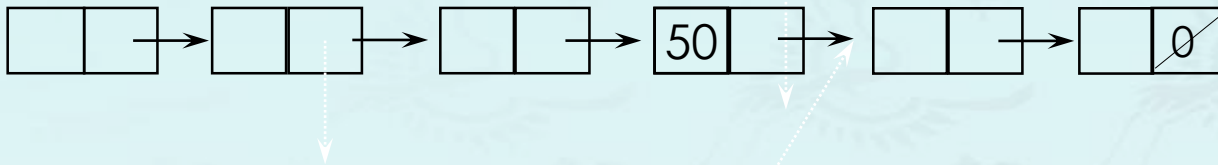
```
struct Node{  
    int data;  
    Node* prev;  
    Node* next;  
    // constructor  
    Node(int d=0, Node* p=nullptr, Node* x=nullptr) {  
        data = d;    prev = p; next = x;  
    }  
    // destructor  
    ~Node() {}  
};
```

can be omitted

Linked List – find()

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

head

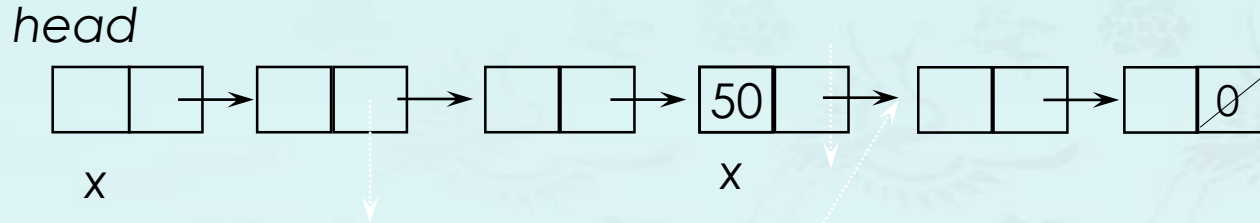


```
pNode find(pNode head, int val)
if (empty(head)) return nullptr;
```

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


Linked List – find()

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



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

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

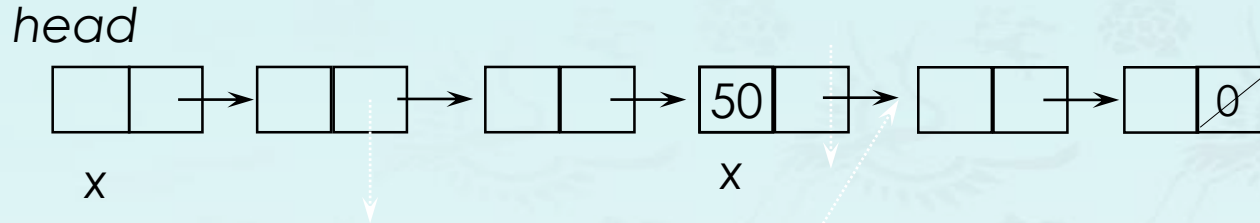
```
pNode find(pNode head, int val)
if (empty(head)) return nullptr;

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

```
bool empty(pNode head)
return head == nullptr;
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Linked List – find()

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return x;
```

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

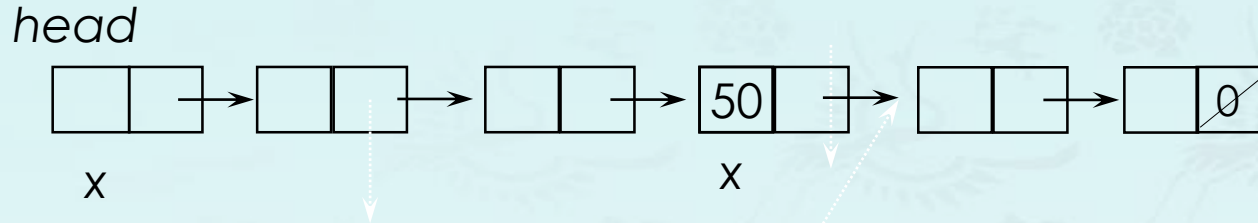
```
pNode find(pNode head, int val)
if (empty(head)) return nullptr;

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



Linked List – find()

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



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

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

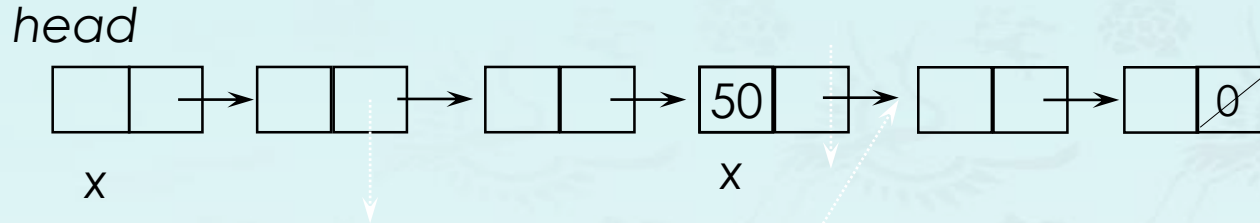
```
bool empty(pNode head)
return head == nullptr;
```

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

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

Linked List – find()

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



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

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

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

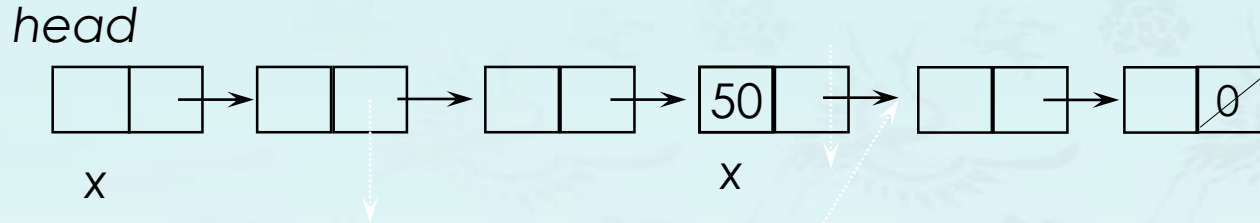
for (pNode x=head; x!=nullptr; x=x->next;){
    if (x->data == val) return x;
}
return x;
```



What is wrong?

Linked List – find()

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



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

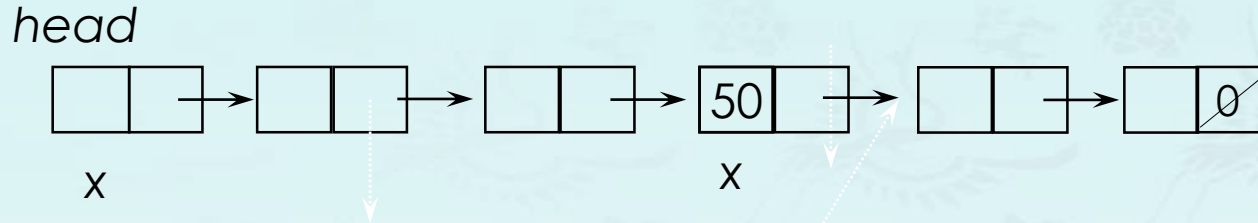
pNode x = head;
while (x != nullptr) {
    if (x->data == val) return x;
    x = x->next;
}
return x;
```

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

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

Linked List – find()

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



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

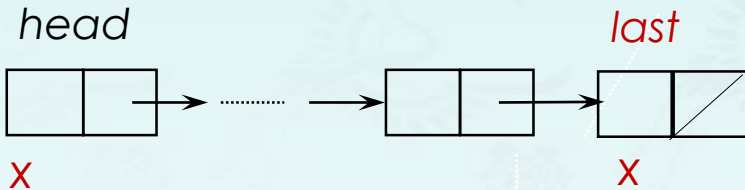
pNode x = head;
while (x != nullptr) {
    if (x->data == val) return x;
    x = x->next;
}
return x;
```

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

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


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 last(pNode head)
```

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

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

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

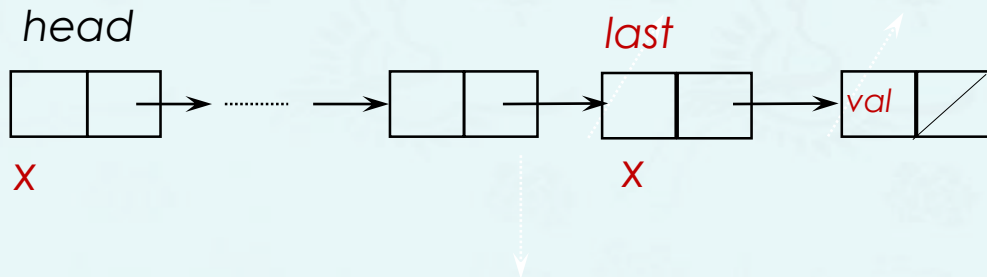
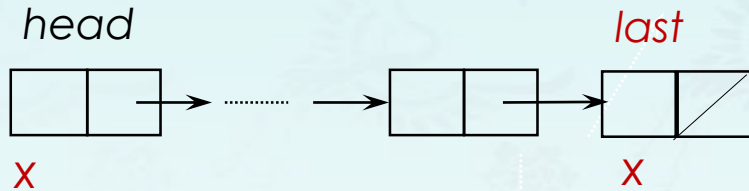
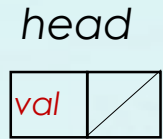
```
pNode last(pNode head)
```

```
pNode x = head;  
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 head, int val)
```

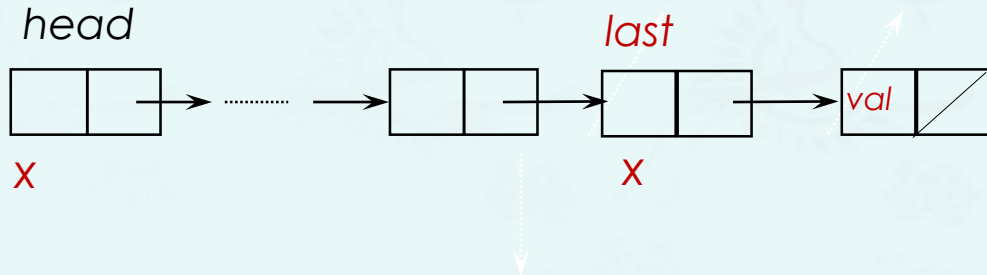
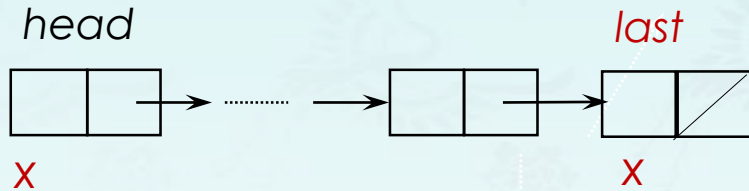
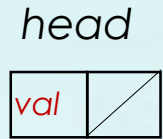
```
if (empty(head))  
    return new Node{val, nullptr};
```

```
pNode last(pNode head)
```

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

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 head, int val)
```

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

```
pNode x = last(head);  
x->next = new Node{val, nullptr};  
return head;
```

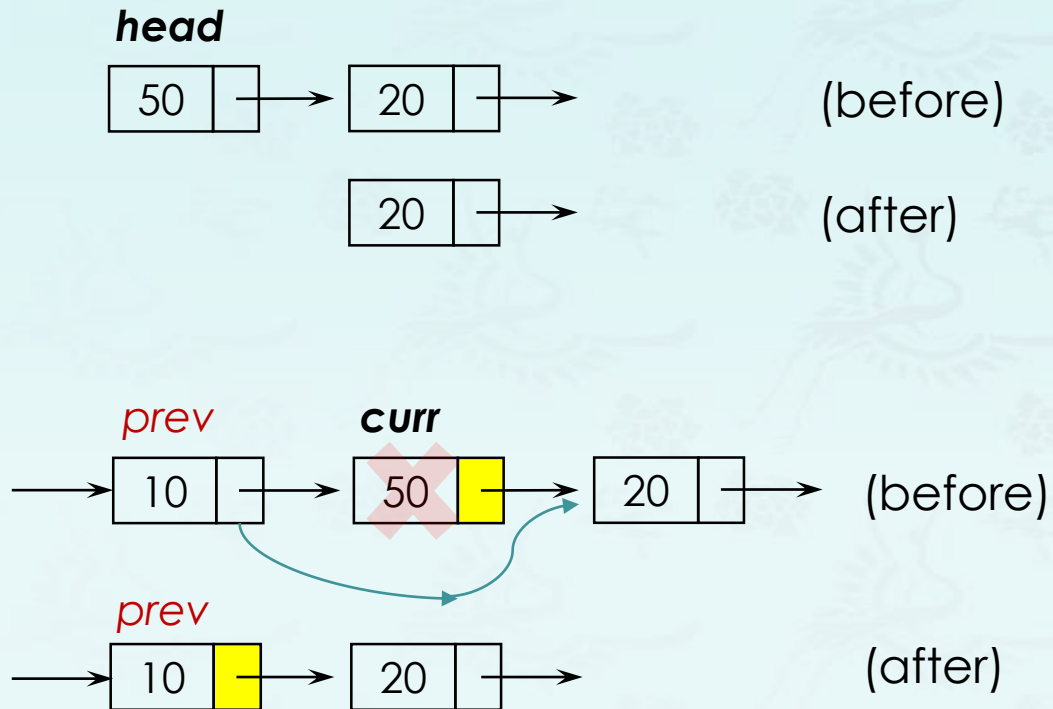
```
pNode last(pNode head)
```

```
pNode x = head;  
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 head, int val)
```

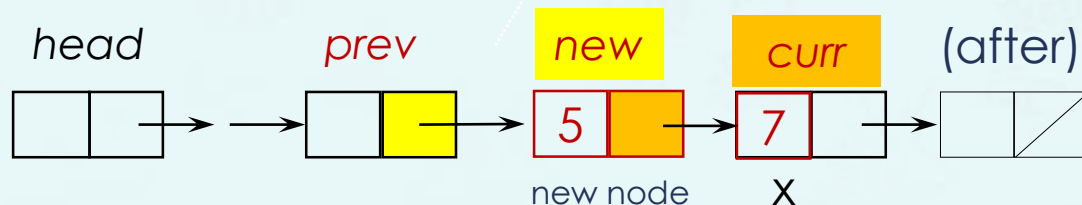
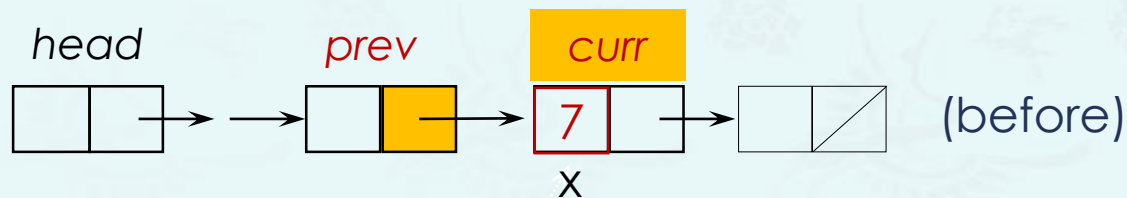
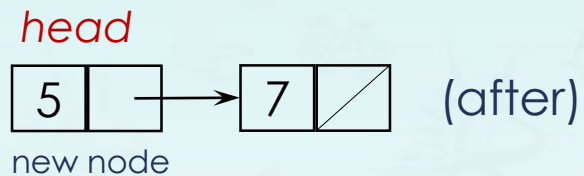
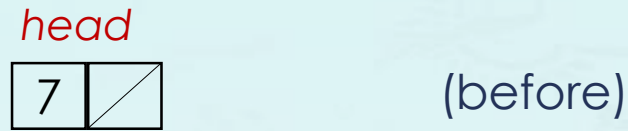
```
if (head->data == val)
    return pop_front(head);

pNode curr = head;
pNode prev = nullptr;
while (curr != nullptr) {
    if (curr->data == val) {
        prev->next = curr->next;
        delete curr;
        return head;
    }
    prev = curr;
    curr = curr->next;
}
return head;
```

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.



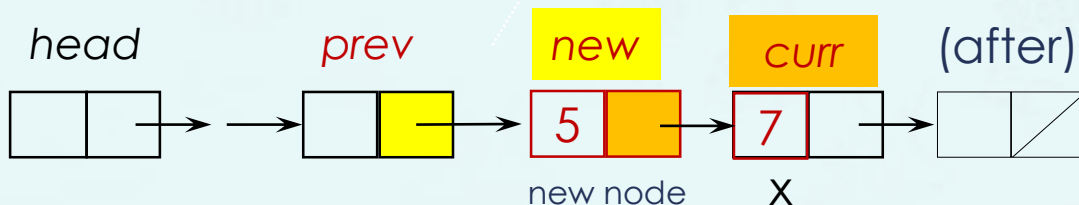
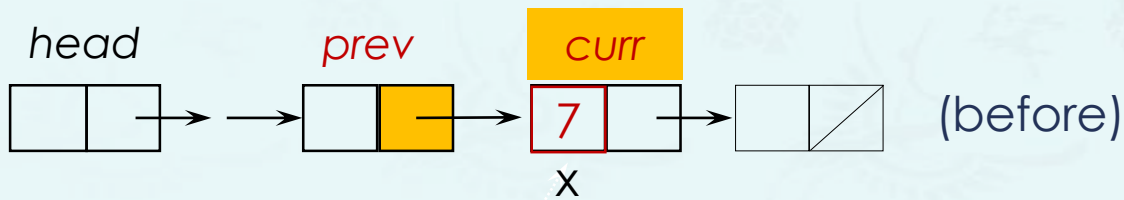
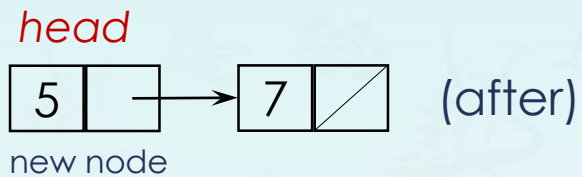
```
pNode insert(pNode head, int val, int x)
{
    if (head->data == x)
        return push_front(val, head);

    pNode curr = head;
    pNode prev = nullptr;
    while (curr != nullptr) {
        if (curr->data == x) {
            [ ] = new Node{ [ ] };
            return head;
        }
        prev = curr;
        curr = curr->next;
    }
    return head;
}
```

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.

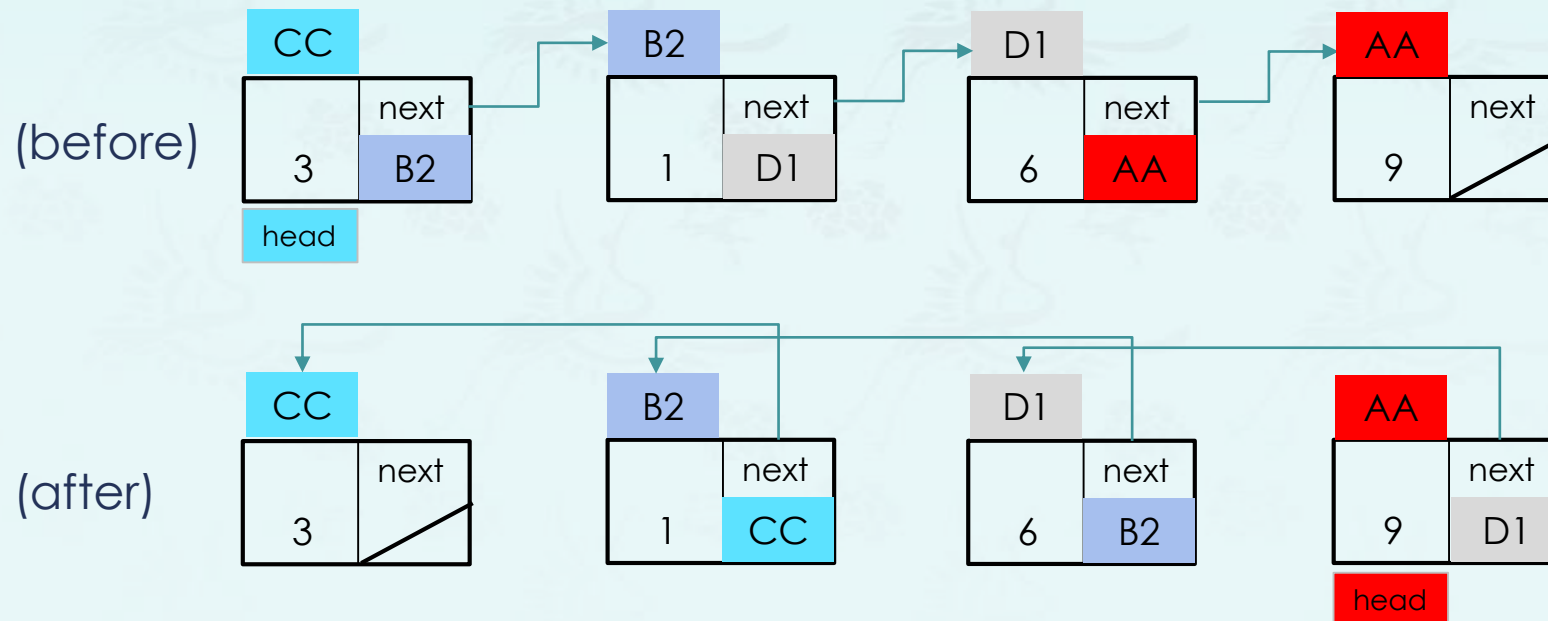


```
pNode insert(pNode head, int val, int x)
{
    if (head->data == x)
        return push_front(val, head);

    pNode curr = head;
    pNode prev = nullptr;
    while (curr != nullptr) {
        if (curr->data == x) {
            prev->next = new Node{val, prev->next};
            return head;
        }
        prev = curr;
        curr = curr->next;
    }
    return head;
}
```


Linked List – reverse()

TASK: reverse a singly linked list in $O(n)$ which goes through the list once.



Linked List – reverse()

TASK: reverse a singly linked list in $O(n)$ which goes through the list once and return the new head.

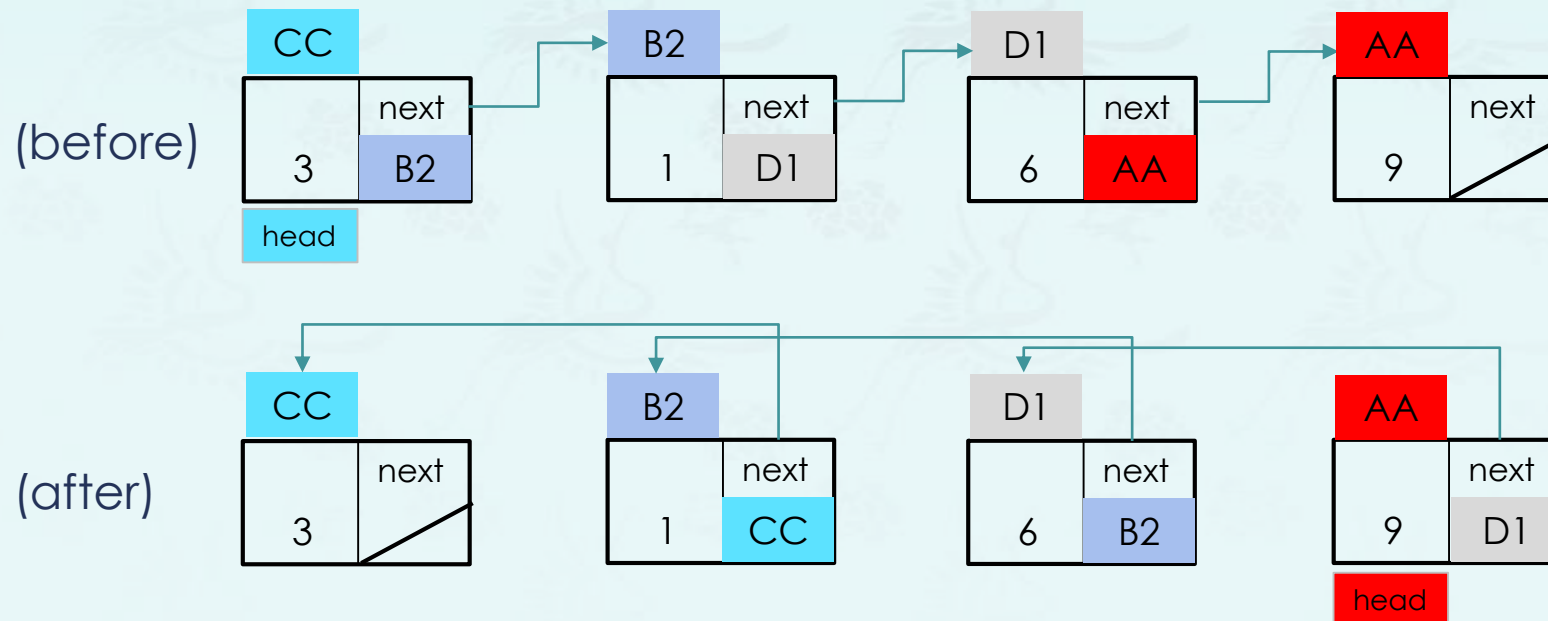
Tips and Hints: Before while() loop, set **prev = nullptr**, and **curr = head**. During while() loop,

(1) Before setting **curr→next** to a new pointer, store the **curr→next** as a temporary node **temp**.

(2) Before going for the next node in while loop, make sure two things:

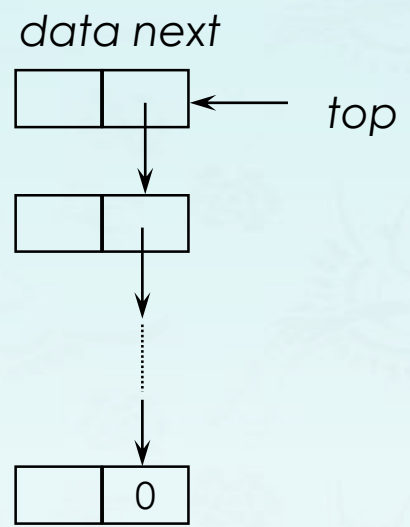
A. set **prev** to **curr** (e.g. **curr** becomes **prev**).

B. set **curr** to the next node you will process.

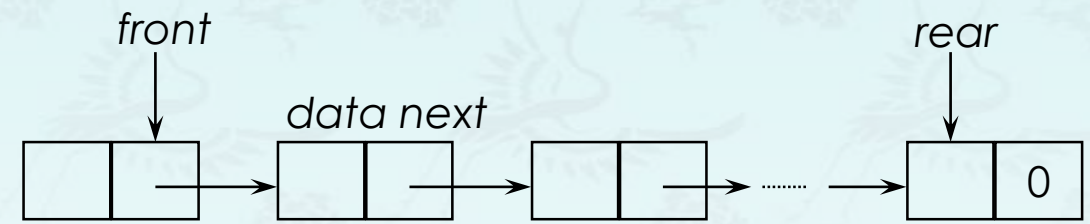


Linked List

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



(a) linked stack



(b) linked queue

Polynomials

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

- **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
------	------	------

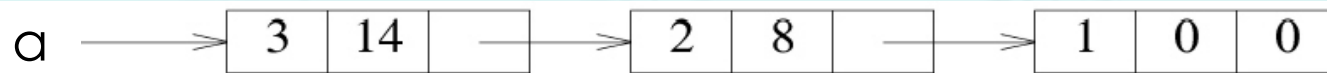
- **Type definition**

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

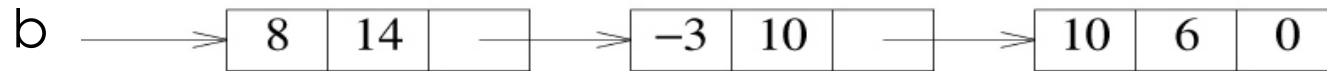
Polynomials

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

- **Example:**



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



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

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

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

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

$$c = a + b$$

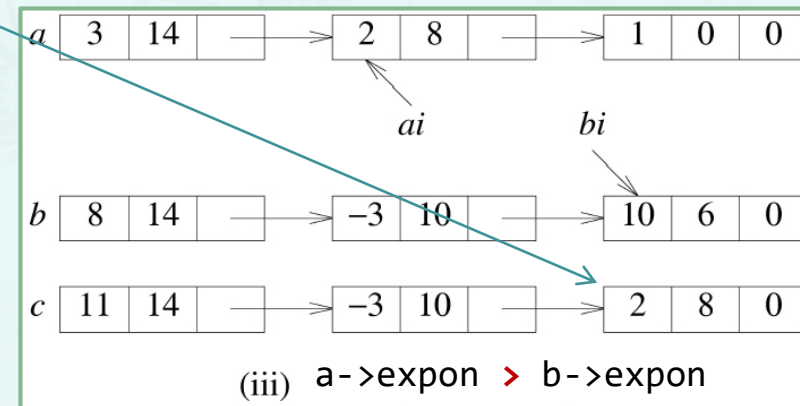
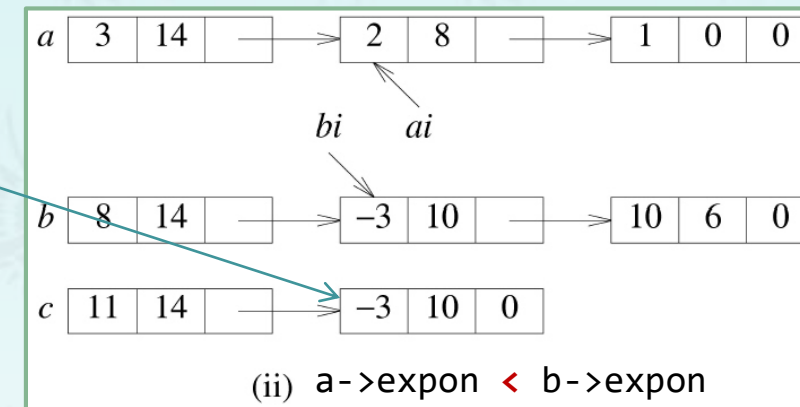
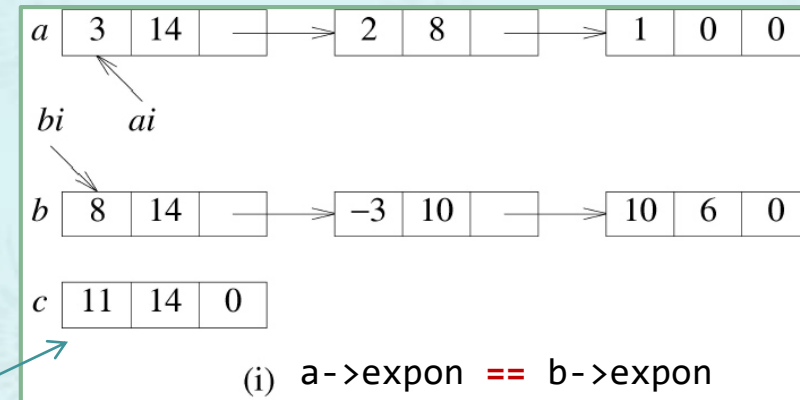
$$= 11x^{14} - 3x^{10} + 2x^8 + 10x^6 + 1$$

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

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

$$c = a + b$$

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



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

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 $O(n)$.

Data Structures

Chapter 4

1. Singly Linked List

- Pointer Reviewed & Linked
- Linked List (1)
- **Linked List (2)**

2. Doubly Linked List

Summary &
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→