Data Structures
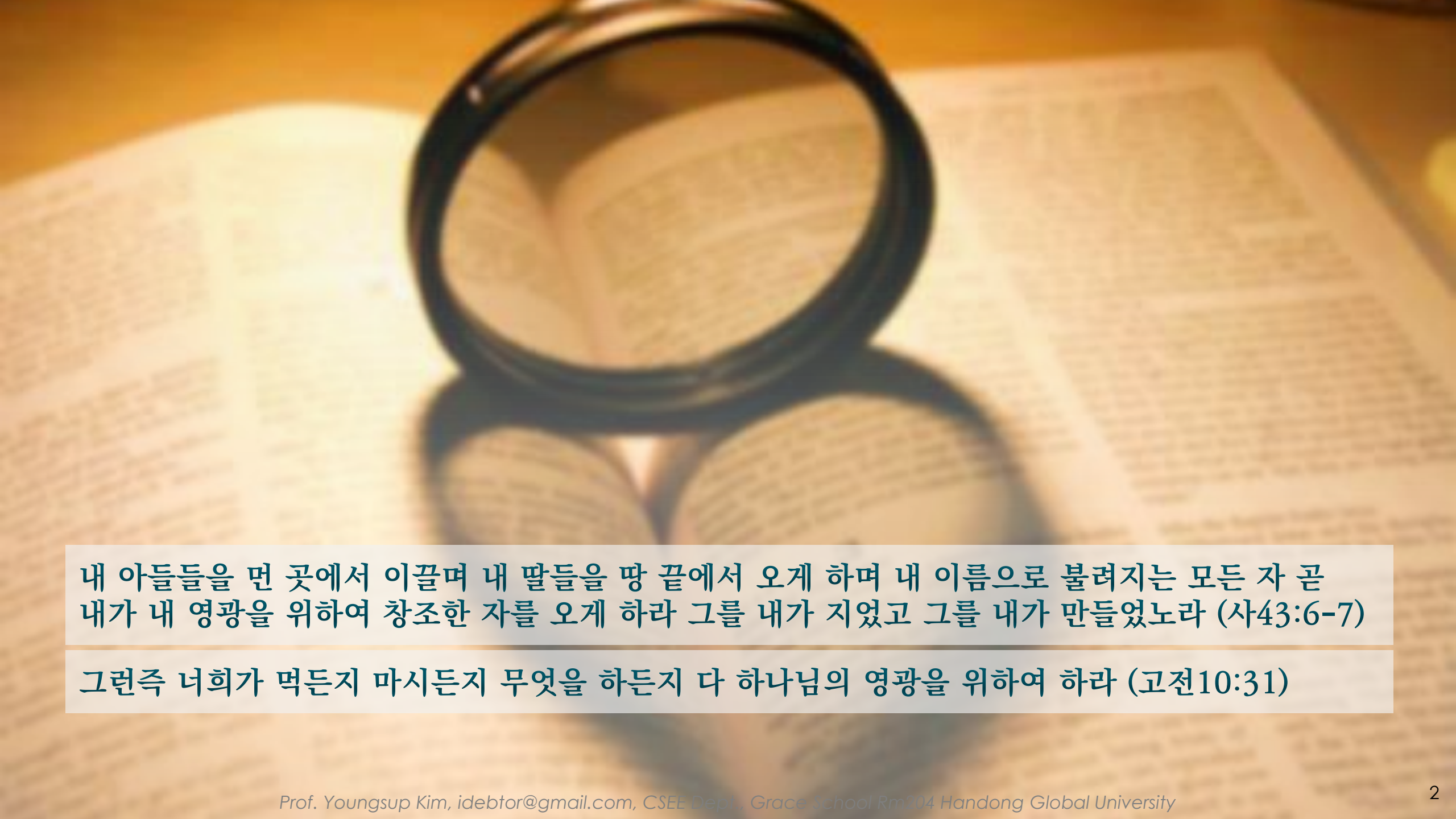**Chapter 4**

1. Singly Linked List
   ◆ Pointer & Linking
   ◆ Singly Linked List (1)
   ◆ **Singly Linked List (2)**
   ◆ Singly Linked List Operations
2. Doubly Linked List

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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)

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Self-Referenced Data Structures

```
class Node {
public:
  int  data;
  Node* next;
};          ⬅  constructor, destructor
```

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Self-Referenced Data Structures

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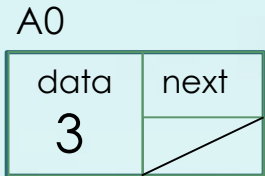
```cpp
struct Node {
  int   data;
  Node* next;

  Node(int i=0, Node* n=nullptr){
    data = i, next = n;
  }
  ~Node() {};
};

int main( ) {
  Node* head, *x, *y;
  Node* p = new Node;
  ...

}
```

```cpp
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"**

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

a new node instantiation

A0

data	next
3	

(1)
```
pNode n = new Node;
```
⟵ no values set
```
Node* n = new Node;
```

(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;          unused in
  Node*  prev;   ⟵     singly linked
  Node*  next;
};

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

a new node instantiation

A0
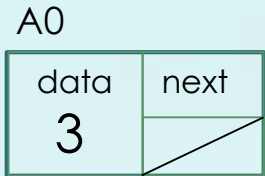
data	next
3	╱

(1)
```
pNode n = new Node(3);

Node* n = new Node(3);
```
❌

{2}
```
Node* n = new Node{3};
```

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

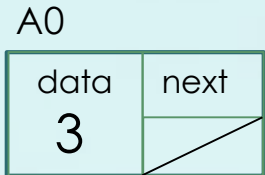{4}
```
Node* n = new Node{3, nullptr, nullptr};
```

```
struct Node {
  int    data;          unused in
  Node*  prev;    ◄──── 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

A0

data	next
3	╱

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

struct List {
  Node*  head;
  Node*  tail;
  int    size; //optional
};
using pNode = Node*;
using pList = List*;
```
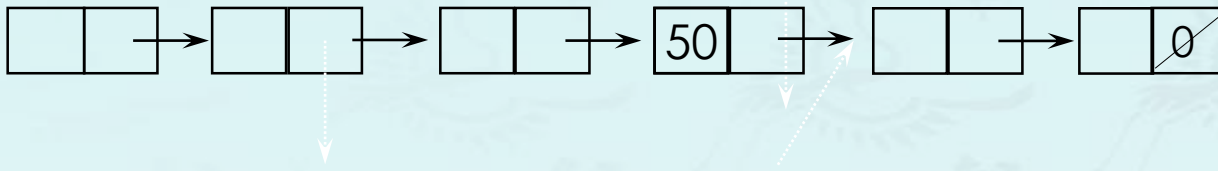
```
pNode n = new Node{3};
```

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

Linked List – find()

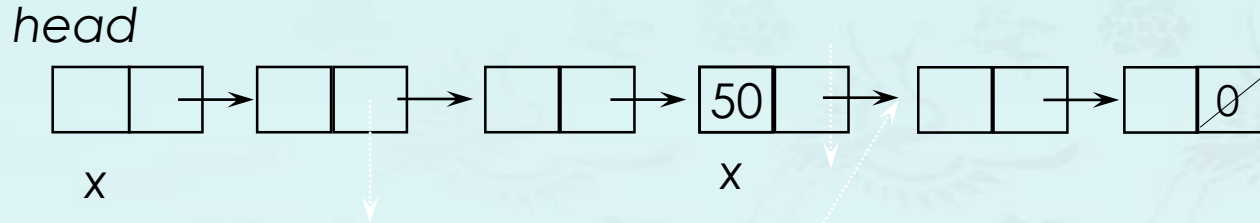**TASK:** Code a function that returns the first node **data = 50** if any, otherwise nullptr.

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.

head


```
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;
```
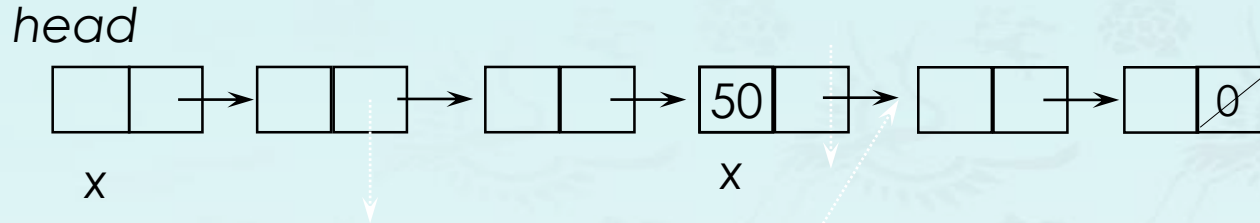
```
pNode find(pNode head, int val)

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;
```

Linked List – find()

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

head

x   x

```
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;
```
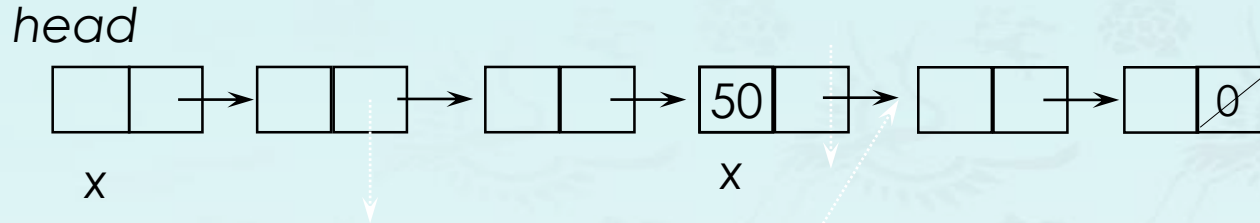
```
pNode find(pNode head, int val)

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;
```

Linked List – find()

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

head

x   x

```
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;


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

```
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.

head

x

x

```
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;
```
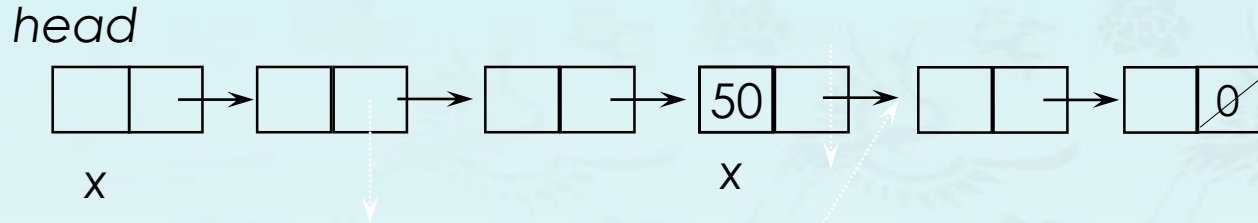
```
pNode find(pNode head, int val)

if (empty(head)) return nullptr;


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

}
return x;
```
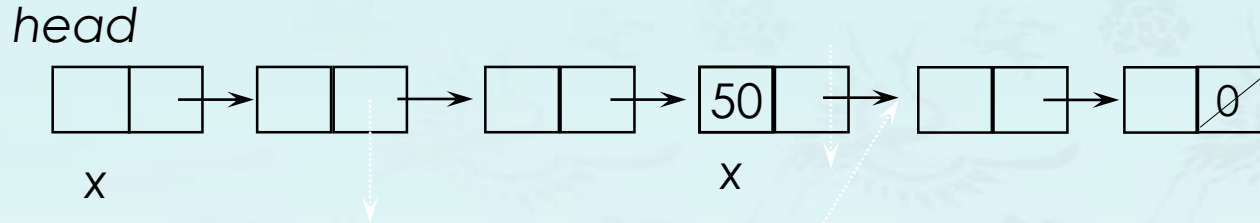
What is wrong?

Linked List – find()

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

head


```
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;
```
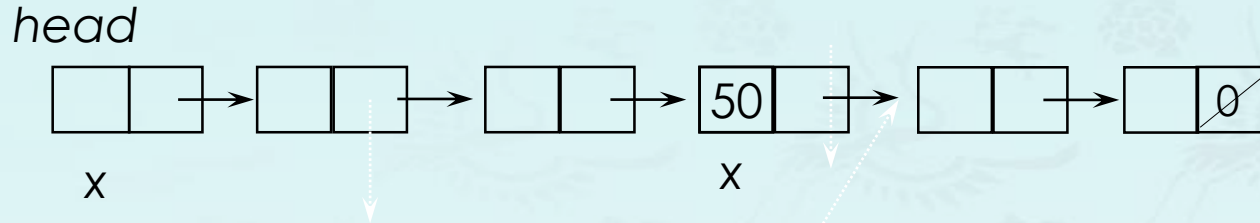
```
pNode find(pNode head, int val)

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.

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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;
```

```
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;
```

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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.

head

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

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

head   *last*

X   X
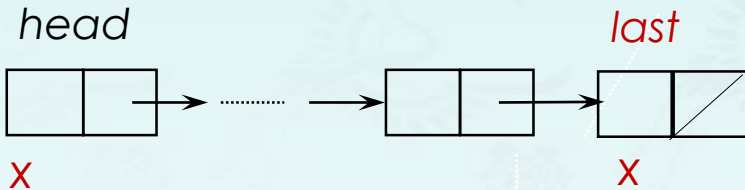
```
pNode last(pNode head)

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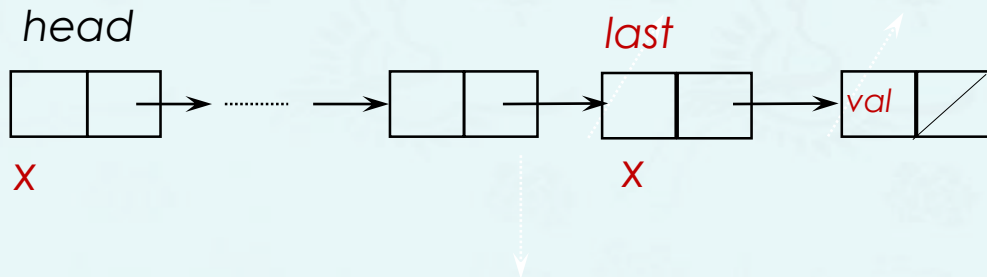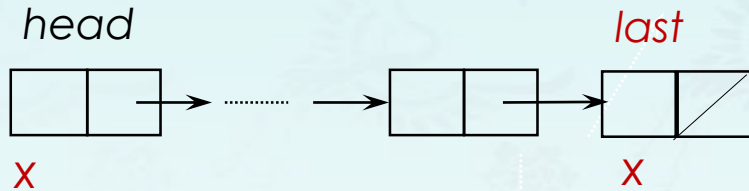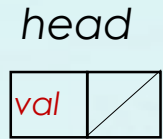
```
pNode last(pNode head)

  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.

head

head   *last*

X   X

head   *last*

X   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;
```

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.
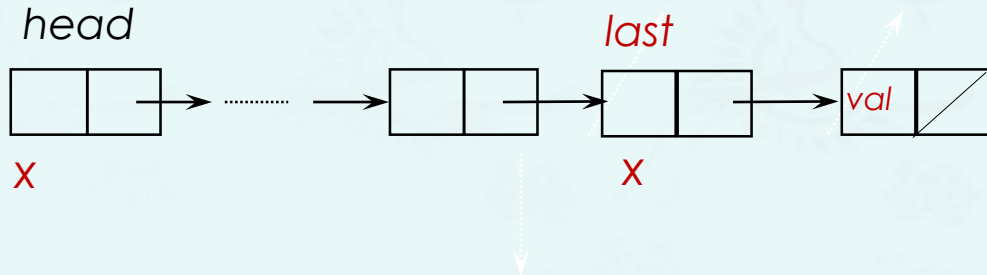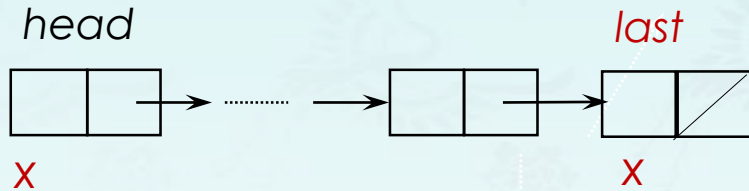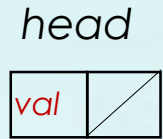


```
pNode push_back(pNode head, int val)

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.

head

50 → 20 →   (before)

20 →   (after)

prev   **curr**

10 → 50 → 20 →   (before)

prev

10 → 20 →   (after)
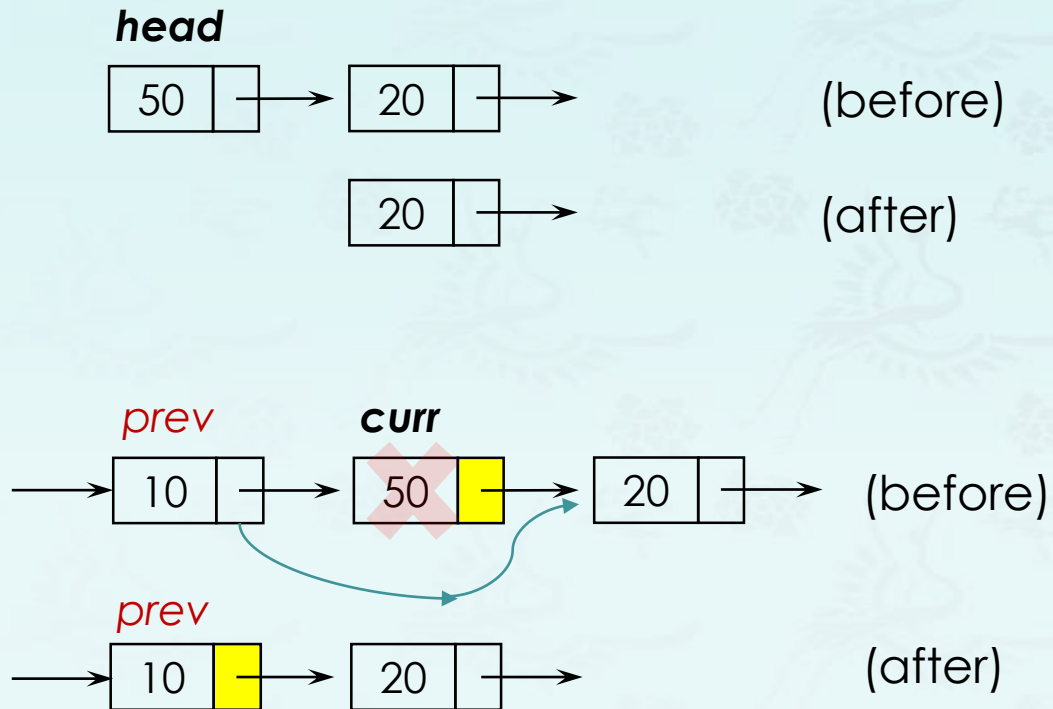
```
pNode pop(pNode head, int val)

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;
```
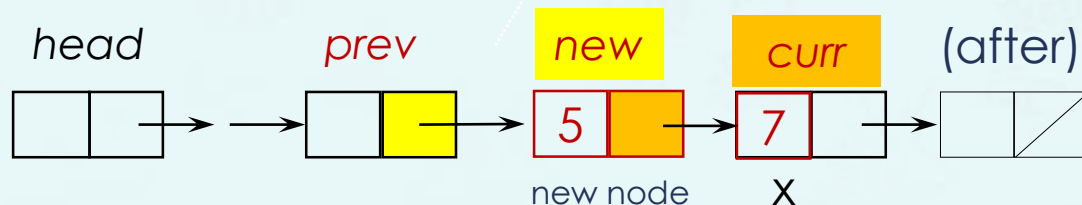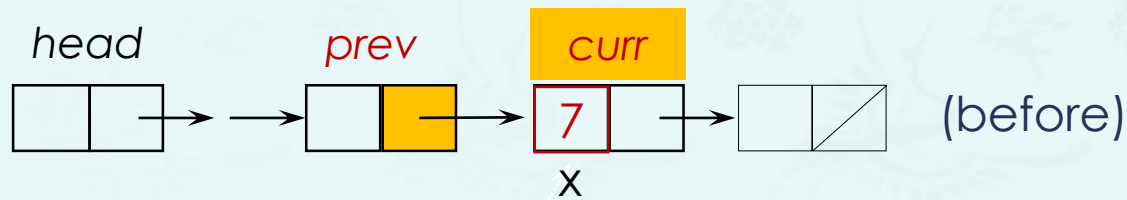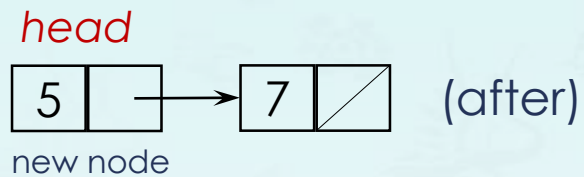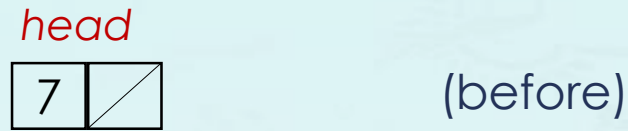
Simplifying this while() loop is
left as a part of Problem Set.

Linked List – insert() or push()

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.
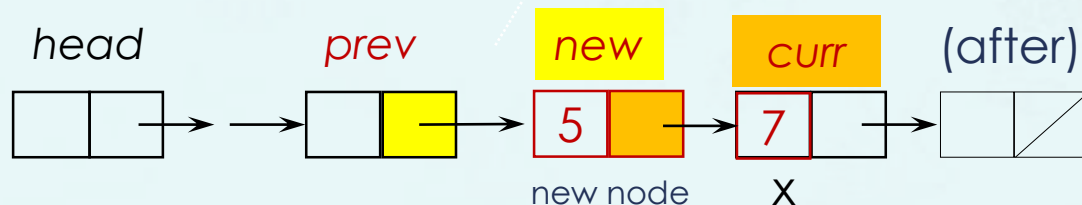
head

| 7 | / |

(before)

head

| 5 | → | 7 | / |

(after)

new node

head   *prev*   **curr**

| | | → | → | | | → | 7 | | → | | / |

(before)

X

head   *prev*   *new*   *curr*

| | | → | → | | | → | 5 | | → | 7 | | → | | / |

(after)

new 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() or push()

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().**
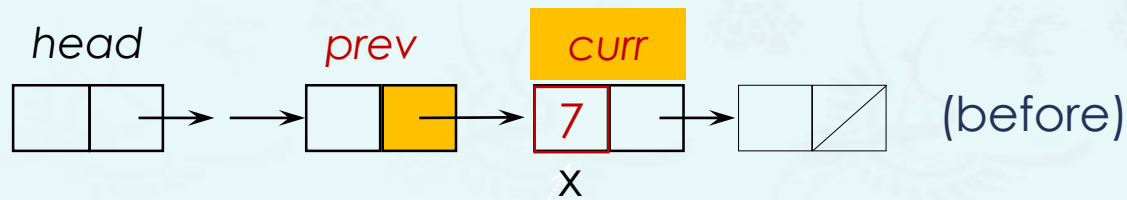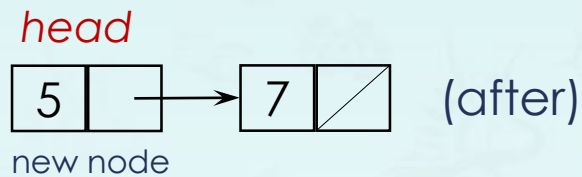- As observed below, we must to know **the pointer x** which is stored in the **previous node** of node x.
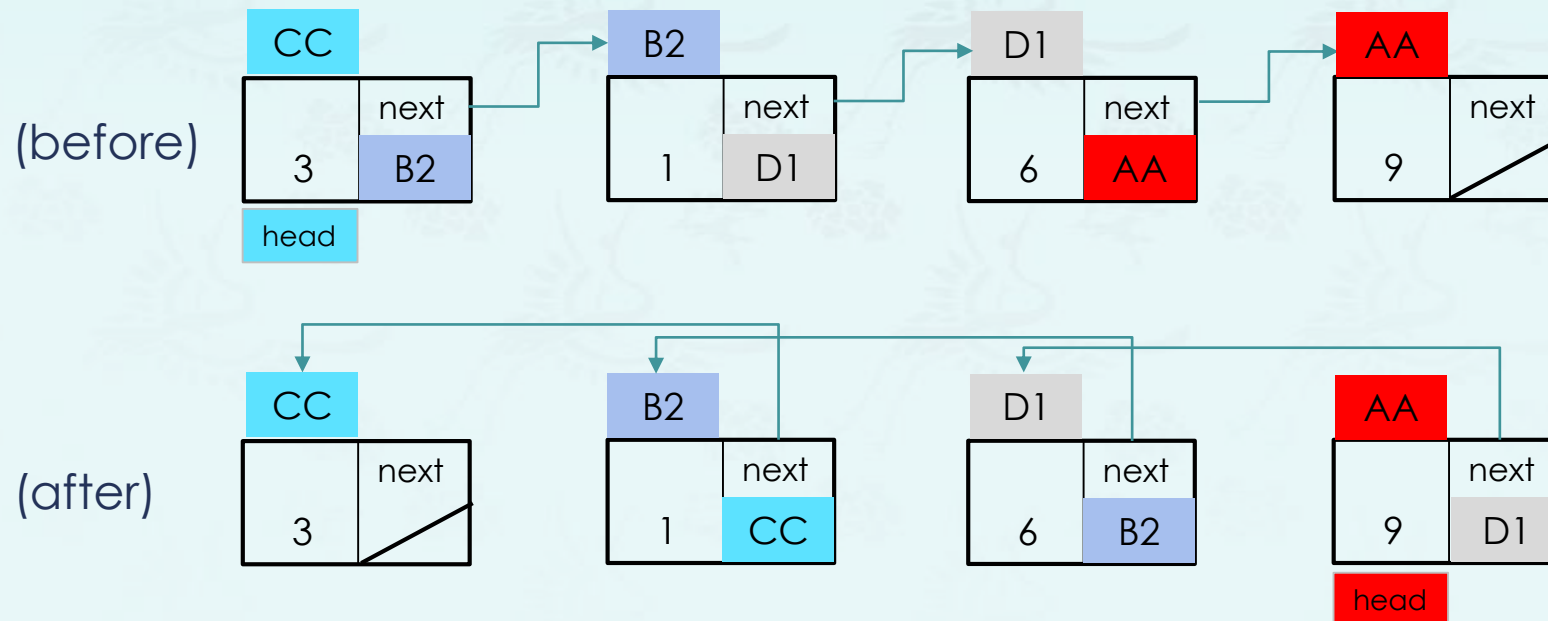
head

| 7 | / |

(before)

head

| 5 | → | 7 | / |

(after)

new node

head   *prev*   *curr*

| | | → → | | | → | 7 | | → | | / |

(before)

X

head   *prev*   *new*   *curr*

| | | → → | | | → | 5 | | → | 7 | | → | | / |

(after)

new 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;
```

Simplifying this while() loop is left as a part of Problem Set.

Linked List – reverse()

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

(before)

(after)

Linked List – reverse()

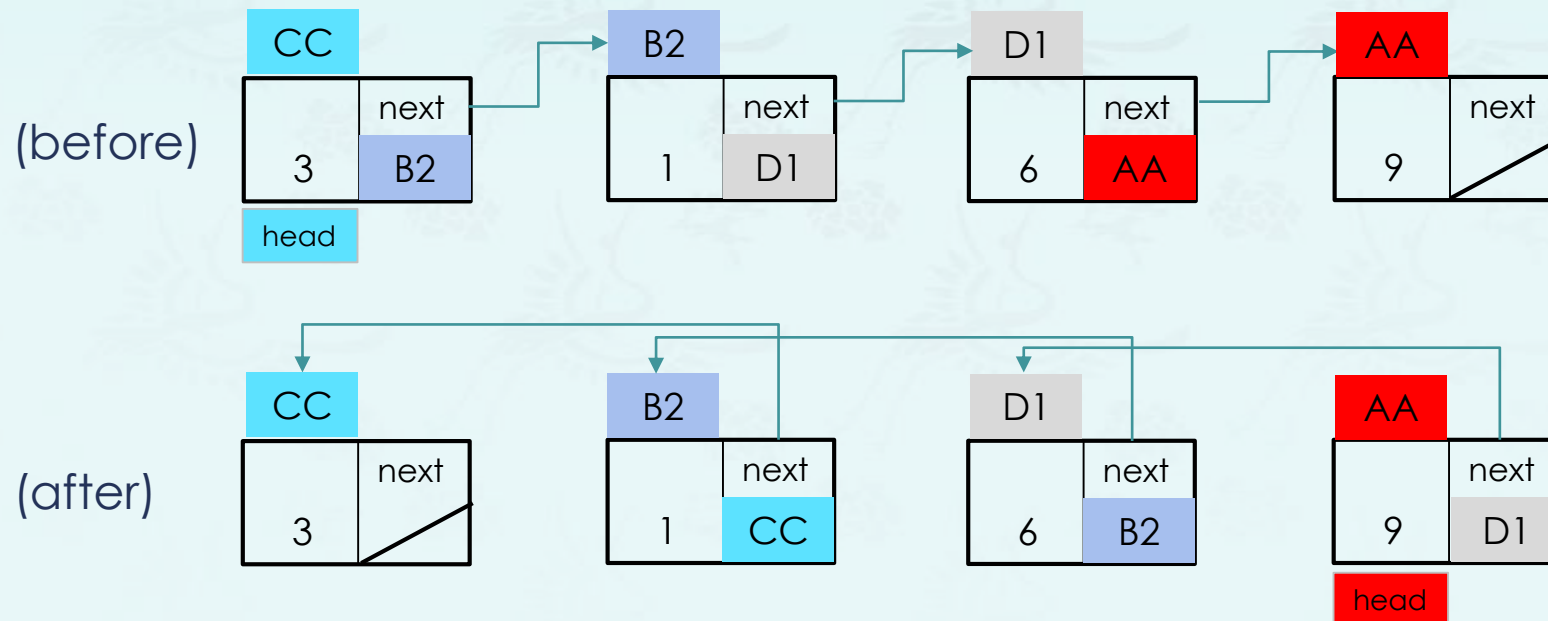**TASK:** reverse a singly linked list in **O(n)** which goes through the list once and return the new head.

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.**
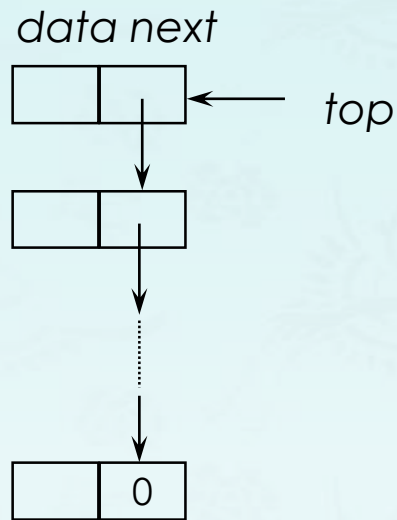(2) Before going for the next node in while loop, make sure two things:
    A. set **prev** to **curr** (e.g. **curr** becomes **prev**).
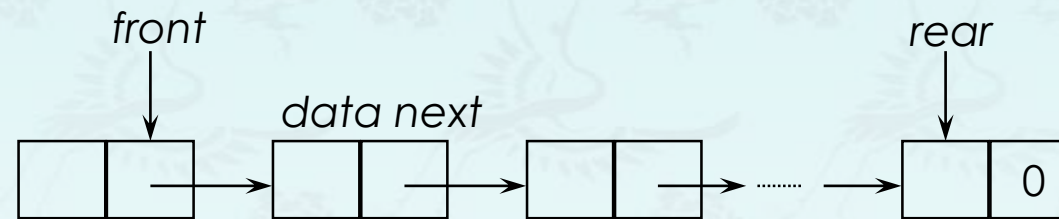   B. set **curr** to the next node you will process.

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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**

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

  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

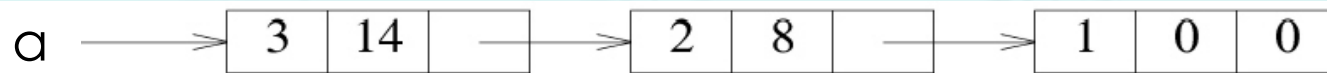- **Type definition**

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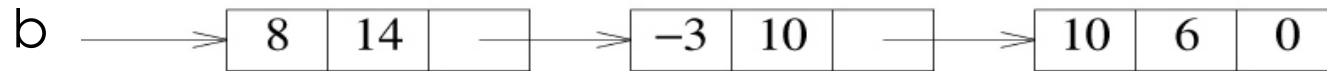
Polynomials

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 = 3x¹⁴ + 2x⁸ + 1
b = 8x¹⁴ - 3x¹⁰ + 10x⁶

c = a + b
  = 11x¹⁴ - 3x¹⁰ + 2x⁸ + 10x⁶ + 1
```

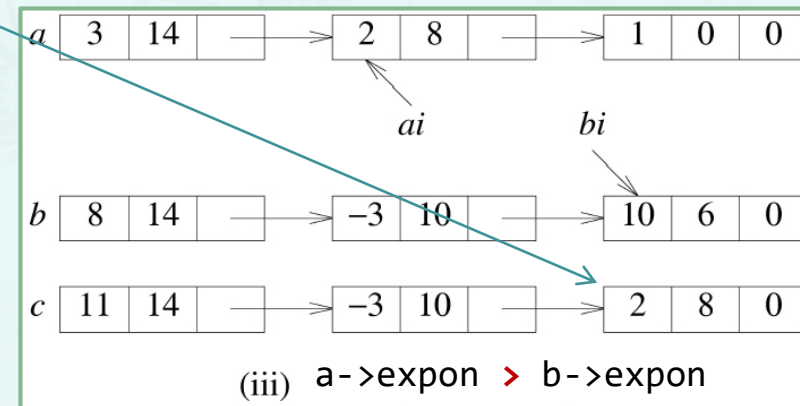$a = 3x^{14} + 2x^8 + 1$
$b = 8x^{14} - 3x^{10} + 10x^6$

$c = a + b$
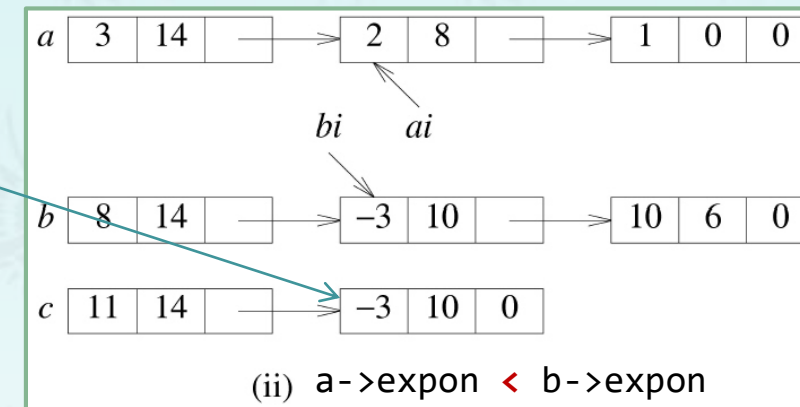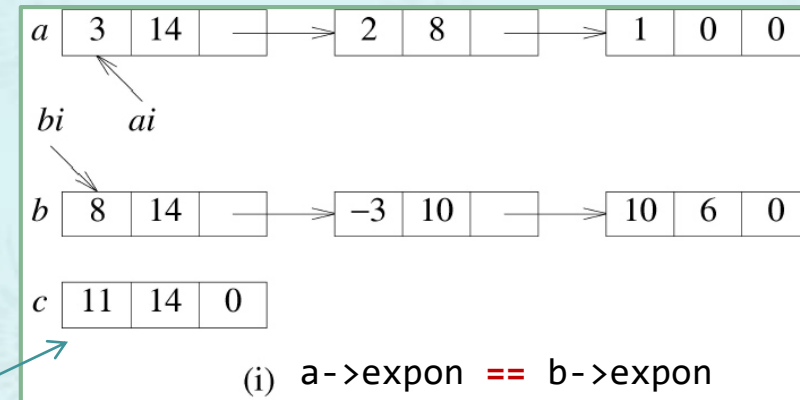$\quad = 11x^{14} - 3x^{10} + 2x^8 + 10x^6 + 1$

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

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

(i) `a->expon == b->expon`

(ii) `a->expon < b->expon`

(iii) `a->expon > b->expon`

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

Summary &

quaestio quaestio quo ? ? ? ?