Linked List

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Contents

- Linked List Concepts.
- Linked List Operations.
- Linked List Improvement.

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- **Linked List Concepts.**
- Linked List Operations.
- Linked List Improvement.

Linked List Concepts

- Limitations of Array:
  - Characteristics:
    - Continuous memory storage.

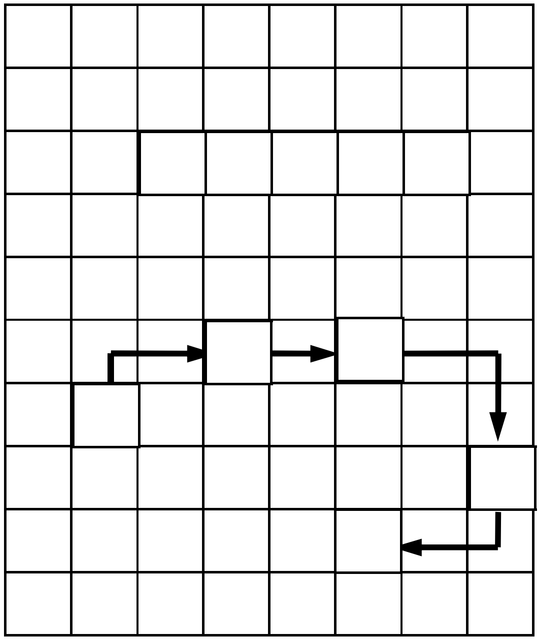
	a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
a	?	?	?	?	?	?	?	?	?	?

  - Advantages:
    - Random element access by indexing.
    - Very efficient for fix-sized storage.
  - Disadvantages:
    - Resize array requires memory reallocation.
    - Add or remove element need element shifted.
    - Allocate large continuous memory is difficult.

Linked List Concepts

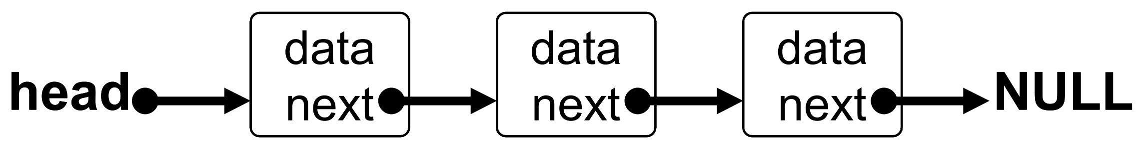
- Linked list solution:
  - Locker renting problem:
    - Need to rent lockers to store N items.
    - Each locker keeps only 1 item.
  - Continuous solution→ Array.
  - Dis-continuous solution:
    - Rent N arbitrary lockers.
    - Each locker keeps:
      - 1 items.
      - Address of next locker.
    - Only keep address of first locker.

Lockers



Linked List Concepts

- Singly linked list:
  - A discontinuous data structure.
  - Element = Data + Link to next element.
  - Last element link to NULL.
  - Head: link to first element.



  - C declaration:

```
struct SNode
{
        int         data;
        SNode   *next;
};
```

```
struct SList
{
        SNode   *head;
};
```

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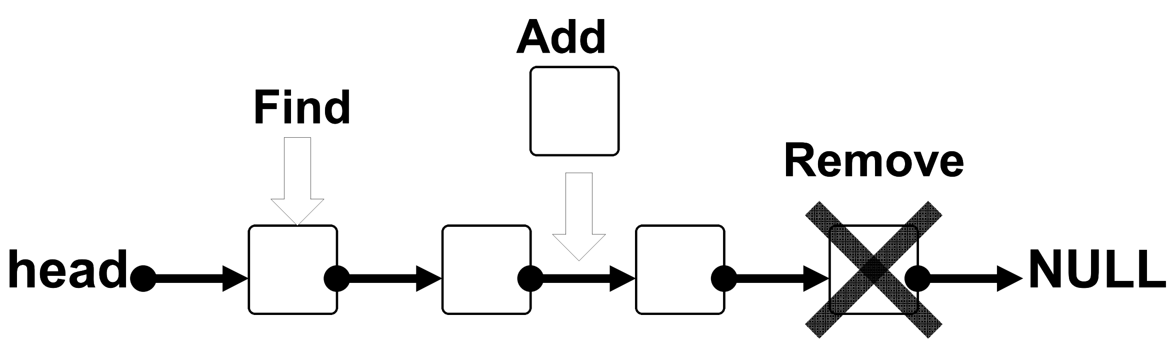
Linked List Operations

- Operations on linked list:
  - Initialize.
  - Check empty.
  - Find element.
  - Add element.
  - Remove element.



Linked List Operations

- Initialize list:
  - At first, list has no element.

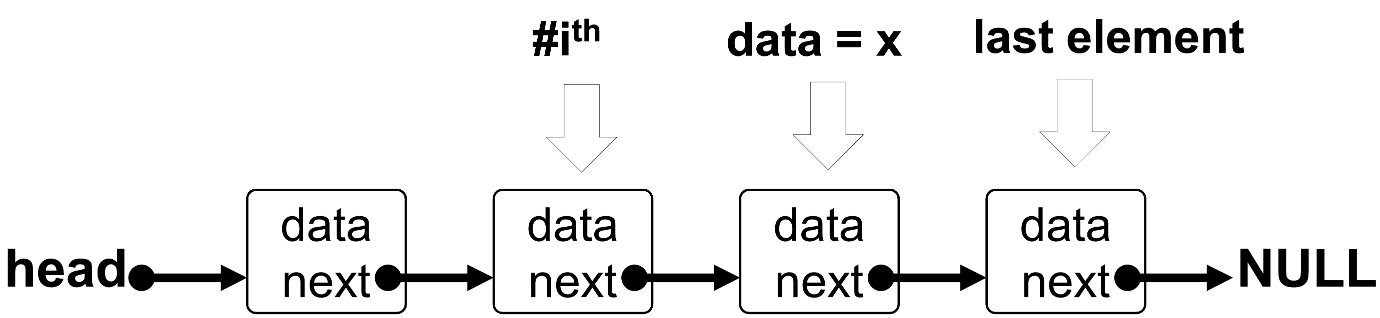
head $\bullet\!\longrightarrow$ **NULL**

- Check empty list:
  - An empty list has no element.

head $\bullet\!\longrightarrow$ **NULL ???**

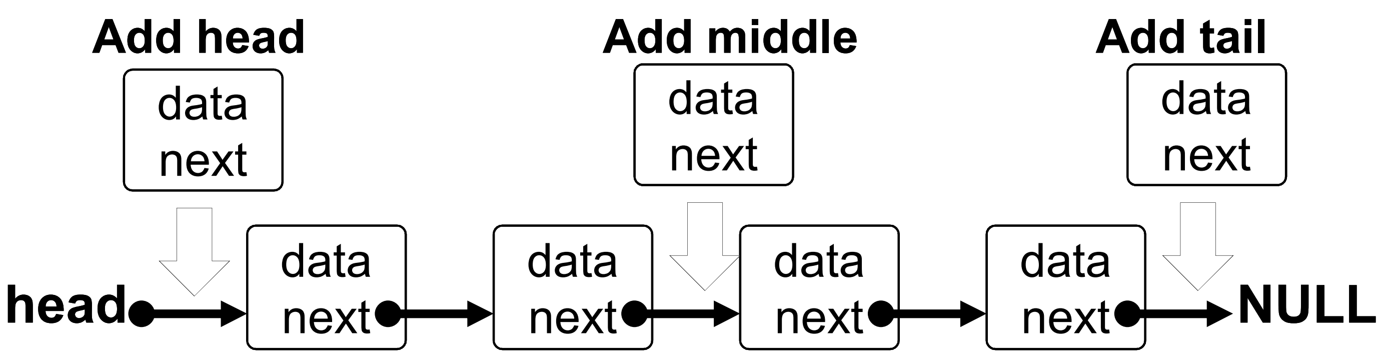
Linked List Operations

- Find element:
  - Find #ith element.
  - Find element has data x.
  - Find last element.



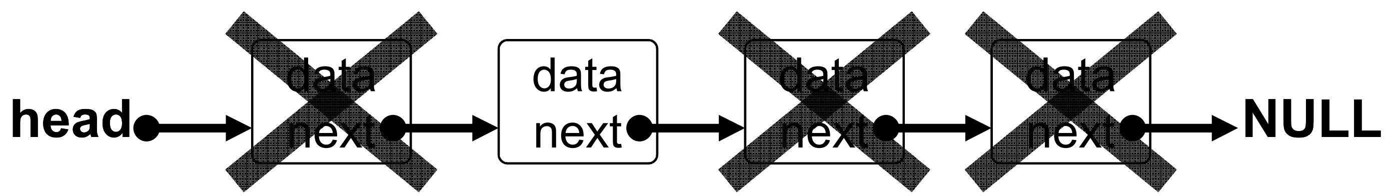
Linked List Operations

- Add element:
  - Add head.
  - Add tail.
  - Add middle:
    - After #ith element.
    - Keep order (ascending).



Linked List Operations

- Remove element:
  - Remove head.
  - Remove tail.
  - Remove middle:
    - #i^{th} element.
    - Element has data x.
  - Remove all.



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- Linked List Concepts.
- Linked List Operations.
- **Linked List Improvement.**

Linked List Improvement

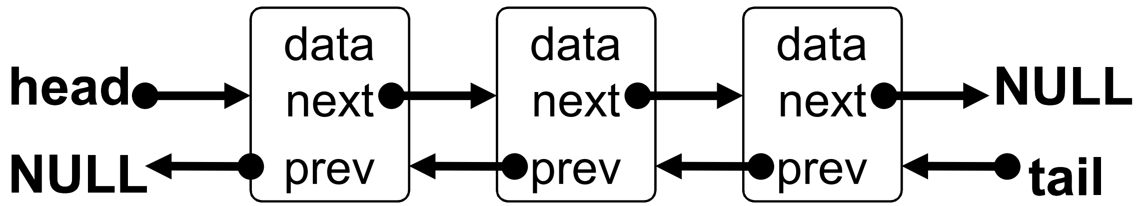
- Singly linked list vs. Dynamic array:

	Dynamic array	**Singly linked List**
Organization	Continuous	Dis-continuous
Resize	Require re-allocation Complexity: **O(n)**	No re-allocation Complexity: **O(1)**
Access element	Random access Complexity: **O(1)**	Sequential access Complexity: **O(n)**
Search	Forward/Backward Complexity: **O(n)**	Forward only Complexity: **O (n)**
Add/Remove element	Require element shifting Complexity: **O(n)**	No shifting Complexity: **O(1)**
Memory cost	No extra memory	Require extra memory Cost: **4 * n bytes**

➔ Efficient way to store ***sequential*** and ***variable-size*** data.

Linked List Improvement

- Doubly linked list:
  - Element = Data + Link to next + Link to previous.
  - Head: forward traverse.
  - Tail: backward traverse.



  - C declaration:

```
struct DNode
{
        int         data;
        DNode       *next;
        DNode       *prev;
};

struct DList
{
        DNode   *head;
        DNode   *tail;
};
```

Linked List Improvement

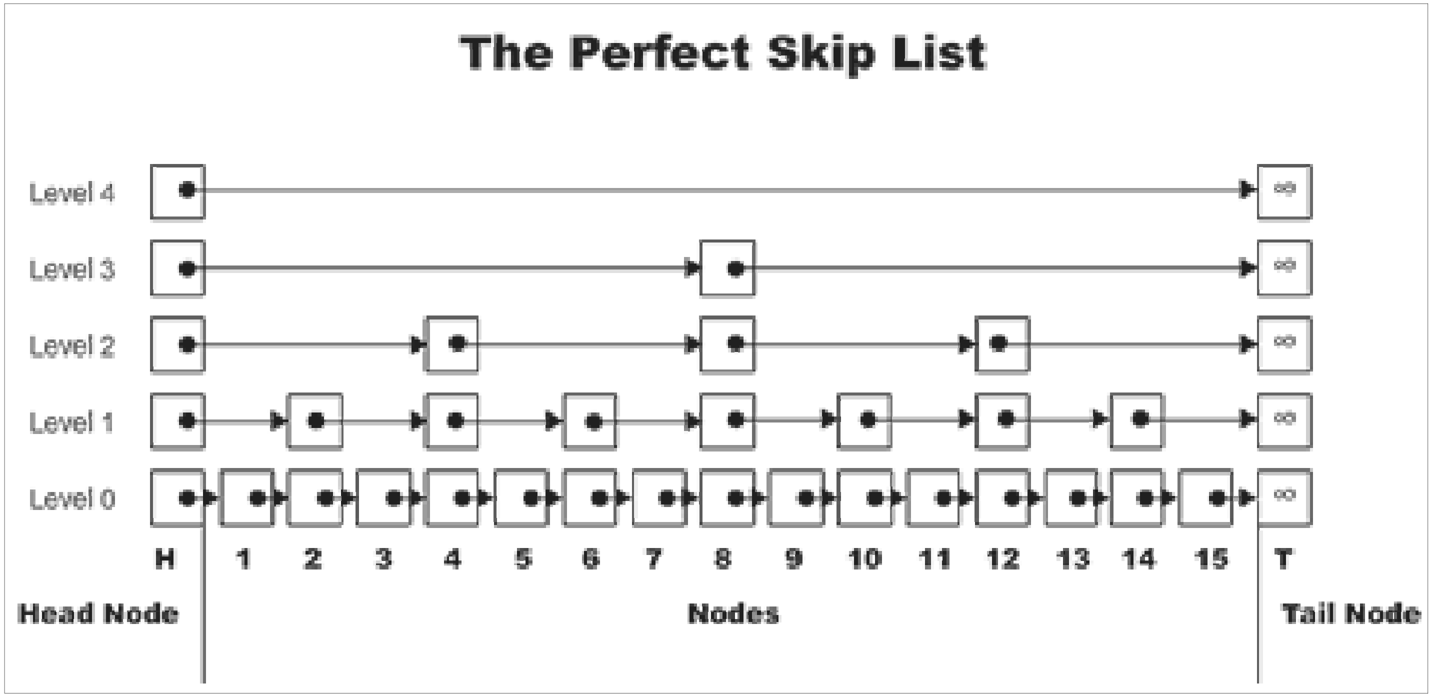
- Doubly linked list vs. Dynamic array:

	Dynamic array	**Doubly linked list**
Organization	Continuous	Dis-continuous
Resize	Require re-allocation Complexity: **O(n)**	No re-allocation Complexity: **O(1)**
Access element	Random access Complexity: **O(1)**	Sequential access Complexity: **O(n)**
Search	*Forward/Backward* *Complexity:* ***O(n)***	*Forward/Backward* *Complexity:* ***O (n)***
Add/Remove element	Require element shifting Complexity: **O(n)**	No shifting Complexity: **O(1)**
Memory cost	*No extra memory*	*Require extra memory* *Cost:* ***8 * n bytes***

➔ Good for ***two-directional traverse***, ***variable-size*** data.

Linked List Improvement

- Skip list:
  - Set of singly linked lists organized in layers.
  - Lower layer: fine-grained nodes, slower “lane”.
  - Higher layer: coarse-grained nodes, faster “lane”.



Linked List Improvement

- Skip list vs. Ordered array:

	Ordered Array	**Skip List**
Organization	Continuous	Dis-continuous
Resize	Require re-allocation Complexity: **O(n)**	No re-allocation Complexity: **O(1)**
Access element	*Random access* *Complexity:* ***O(1)***	*Sequential access* *Complexity:* ***O(log(n))***
Binary search	*Forward/Backward* *Complexity:* ***O(n*log(n))***	*Forward only* *Complexity:* ***O (n*log(n))***
Add/Remove element	Require element shifting Complexity: **O(n)**	No shifting Complexity: **O(1)**
Memory cost	No extra memory	Require extra memory Cost: **log(n) * 4 * n bytes**

➔ Efficient way to store ***variable-size*** and ***ordered*** data.

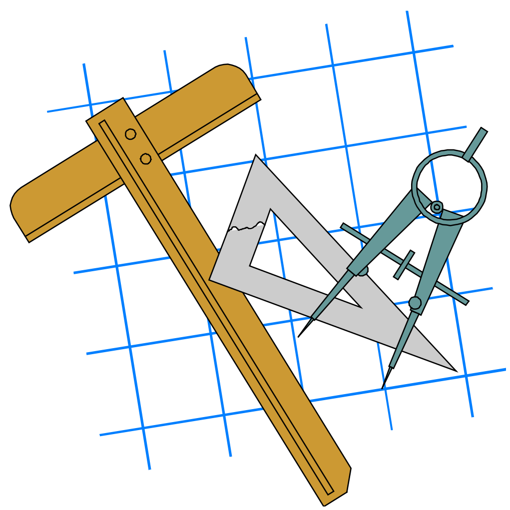
Summary

- Singly linked list concepts:
  - Dis-continuous storage.
  - Node = data + next.
  - Last node points to NULL.
- Singly linked list operations:
  - Initialize, check empty.
  - Find, add, remove.
- Singly linked list improvements:
  - Doubly linked list.
  - Circularly linked list.

Practice

- ## Practice 8.1:

  Write C program to implement operations on Doubly and Circularly linked lists as mentioned in slides.



Practice

- Practice 8.2:

  Write C program to implements the following operations on Singly linked list:

  - Count nodes in list.
  - Reverse list.
  - Add new node (keep order).