CMSC 132: OBJECT-ORIENTED PROGRAMMING II

Linear Data Structures

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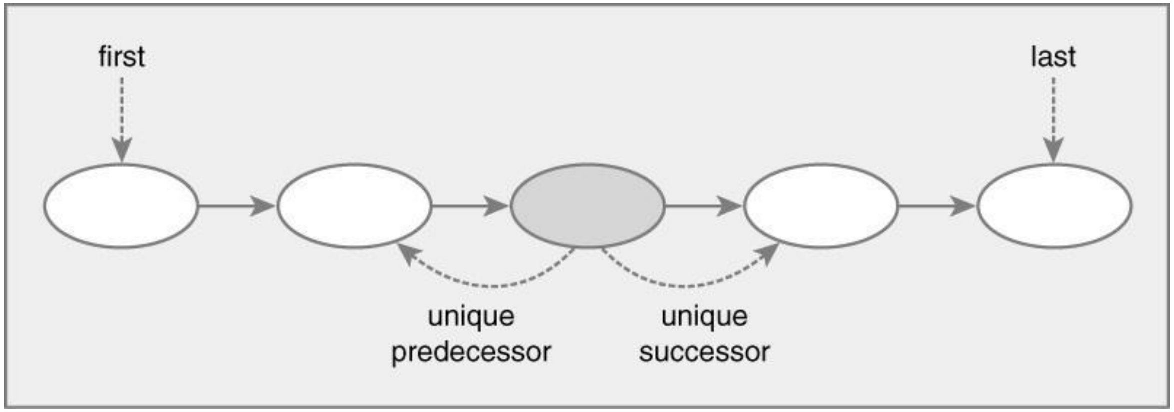
Linear Data Structures

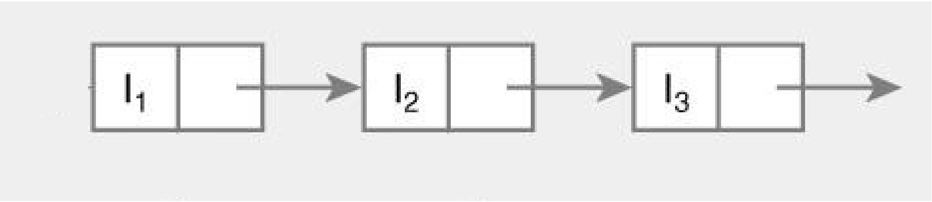
- 1-to-1 relationship between elements
  - Each element has unique predecessor & successor
  - Results in total ordering over elements
  - For any two distinct elements x and y, either x comes before y or y comes before x
  - Beginning of the list identified with first/head
  - End of the list identified with last/tail



List Implementations

- Two basic implementation techniques for lists
  - Store elements in an array
  - Store as a linked list
    - Place each element in a separate object (node)
    - Node contains reference to other node(s)
    - Link nodes together

```
Class Node {
        Object data;
        Node next;
}
```



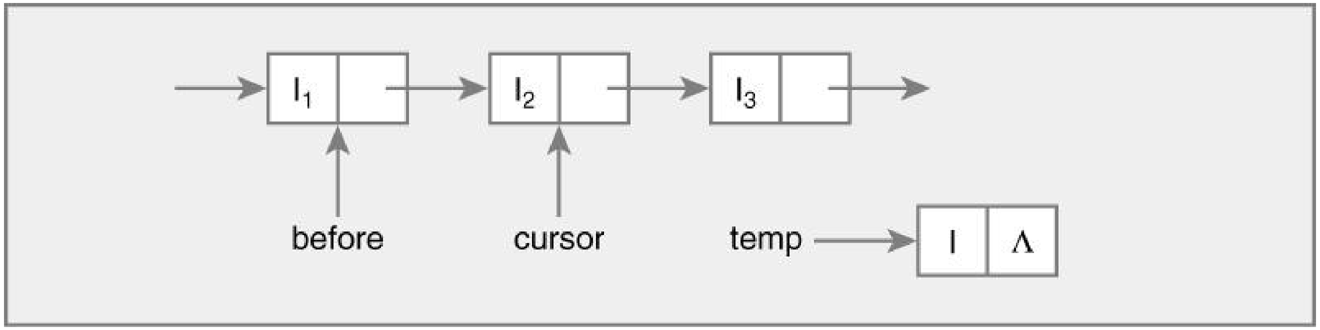
    - Node head → points to first node

Array vs. LinkedList Implementations

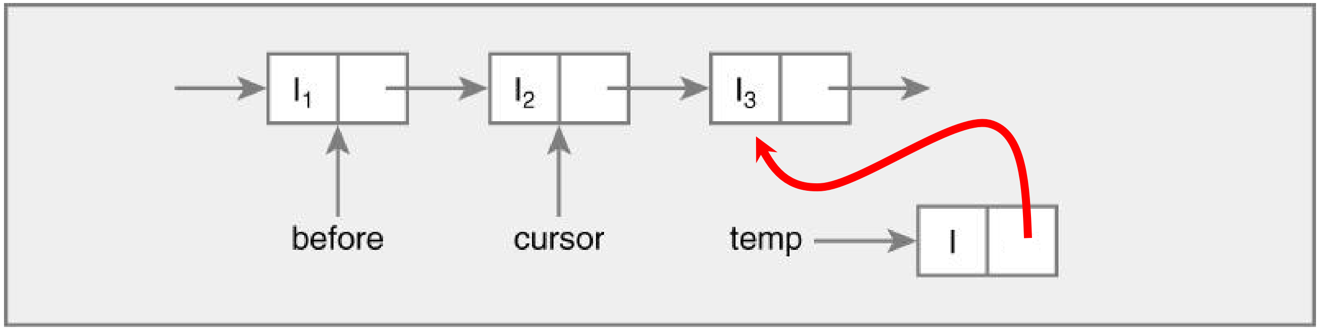
- Arrays
  - Advantages
    - Can efficiently access element at any position (O(1))
    - Efficient use of space (space just to hold reference to each element)
  - Disadvantages
    - Expensive to grow / shrink array
      - Can amortize cost (grow / shrink in spurts)
    - Expensive to insert / remove elements in middle (O(n))
    - Tricky to insert / remove elements at both ends
- LinkedList
  - Advantages
    - Can efficiently insert / remove elements anywhere
  - Disadvantages
    - Cannot efficiently access element at any position
      - Need to traverse list to find element (O(n))
    - Less efficient use of space
      - 1-2 additional references per element
- **Example:** See LinkedList code distribution

Linked List – Insert (After Cursor)

1. Original list & new element temp

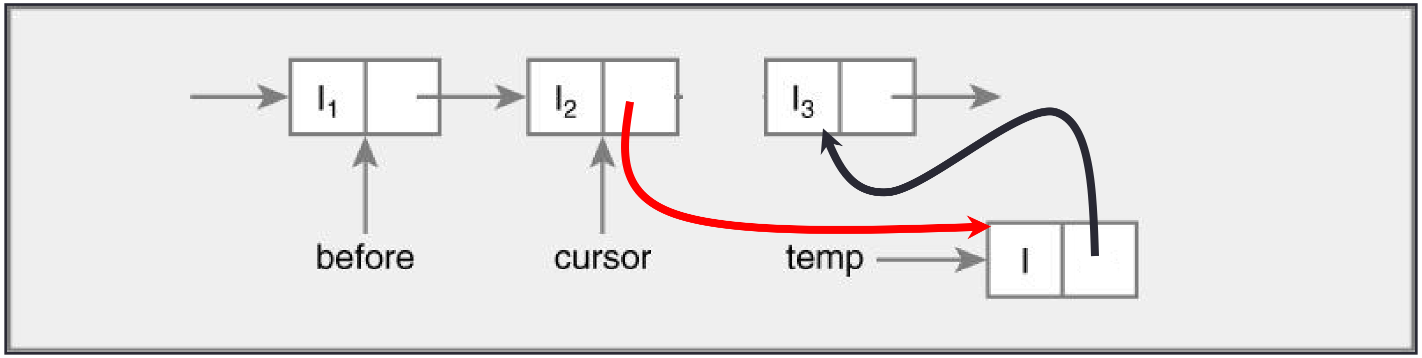


2. Modify temp.next → cursor.next

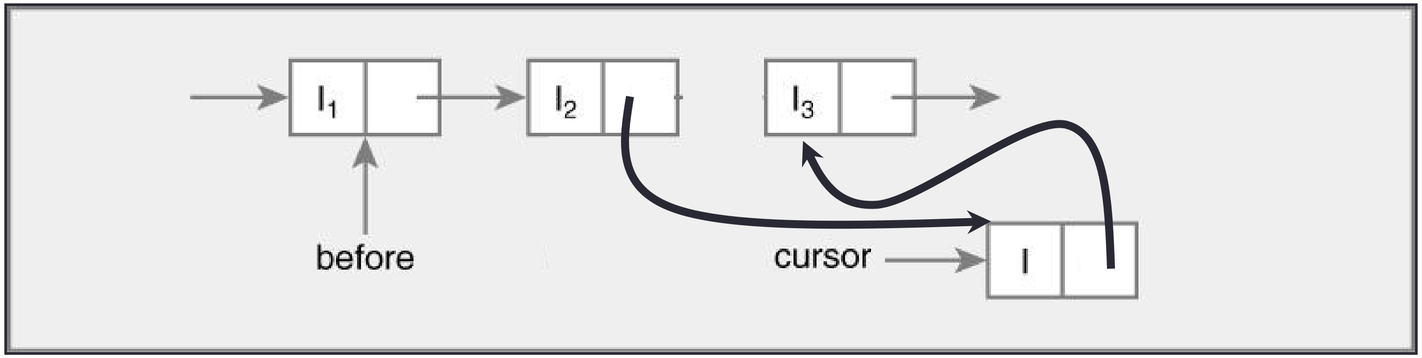


Linked List – Insert (After Cursor)

3. Modify cursor.next → temp

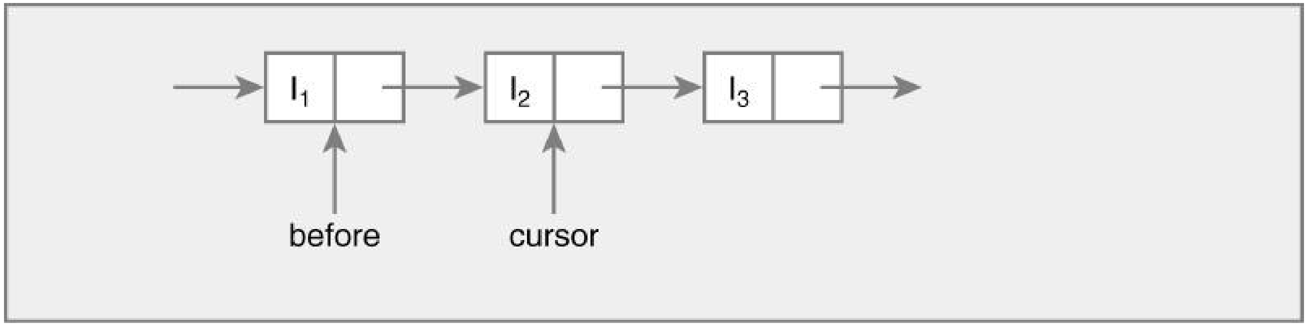


4. Modify cursor → temp

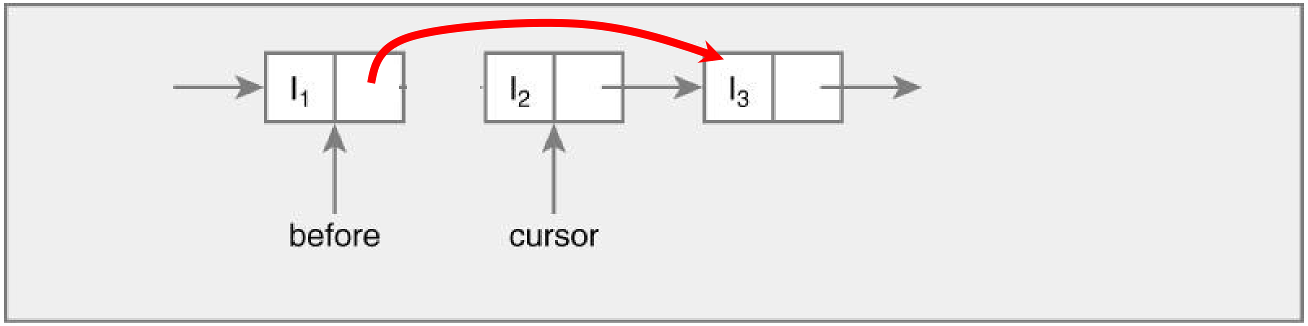


Linked List – Delete (Cursor)

1. Find before such that before.next = cursor

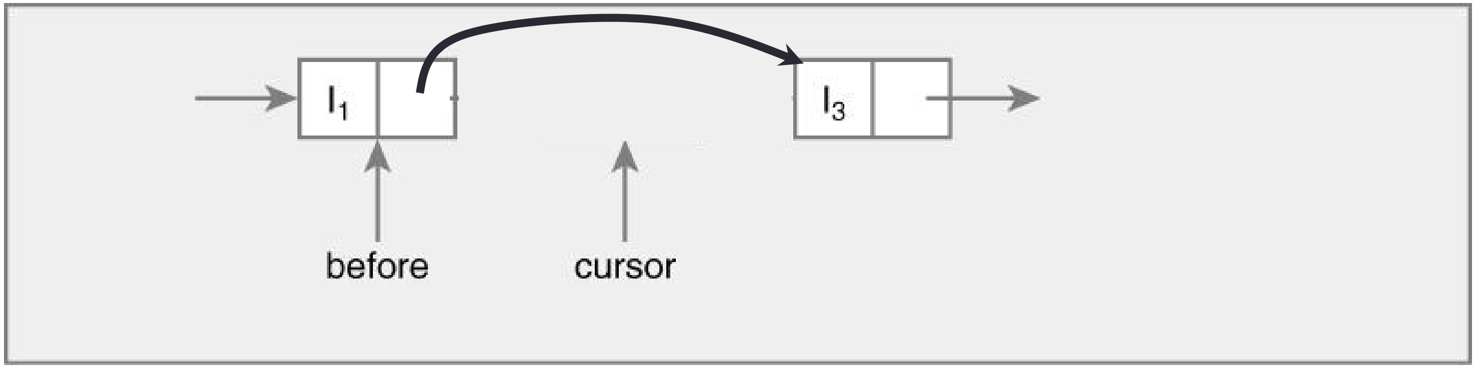


2. Modify before.next → cursor.next

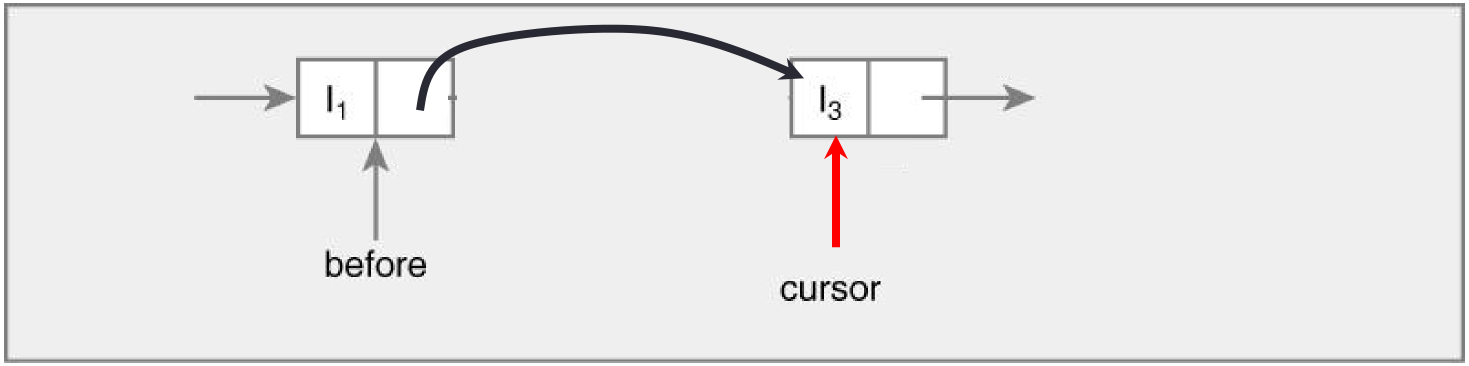


Linked List – Delete (Cursor)

3. Delete cursor



4. Modify cursor → before.next

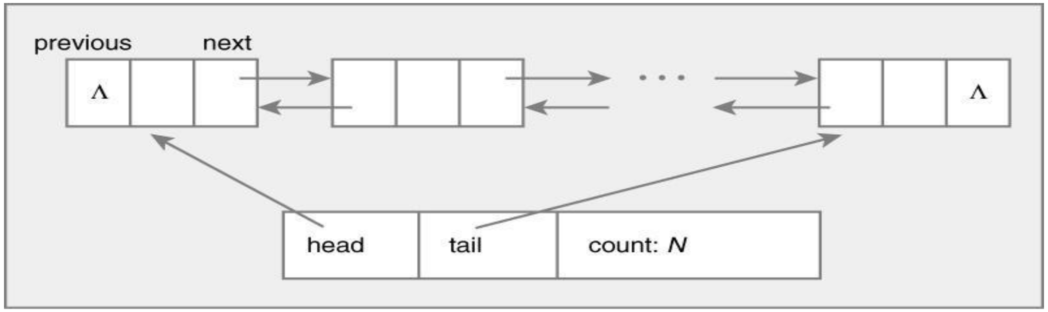


Maintaining List Sorted

- One approach to maintain a linked list sorted with every insertion is
  - If the list is empty
    - Just make the element the first of the list (insertion is trivial)
  - Otherwise
    - Traverse the list until you find an element (B) larger than the one you want to insert (A)
    - Once you find B, insert A before B
    - If you don’t find B, A will become the last element of the list

Doubly Linked List

- Linked list where element has predecessor & successor



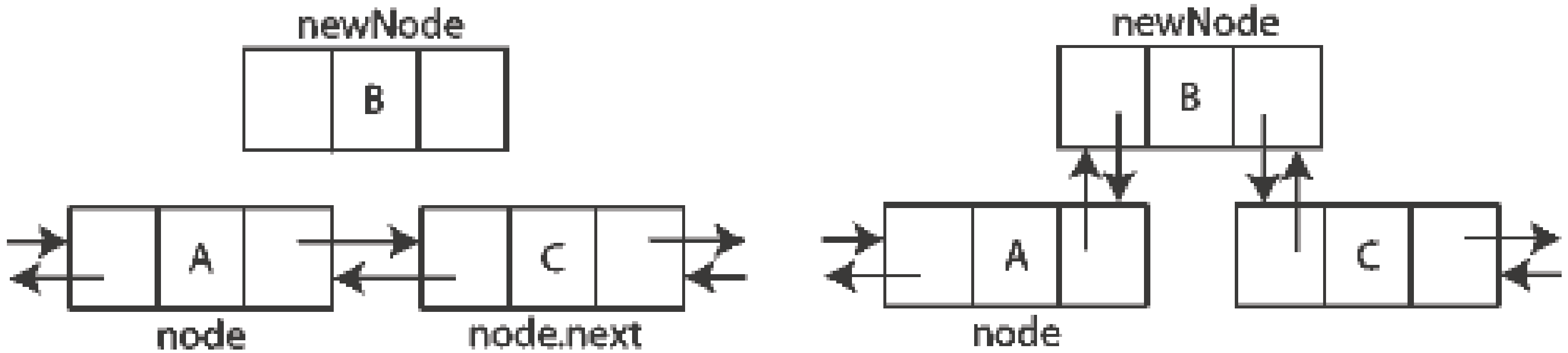
- **Structure**

```
Class Node {
    Object data;
    Node next;
    Node previous;
}
```

- **Issues**
  - Easy to find preceding / succeeding elements
  - Extra work to maintain links (for insert / delete)
  - More storage per node

Doubly Linked List – Insertion

- Example



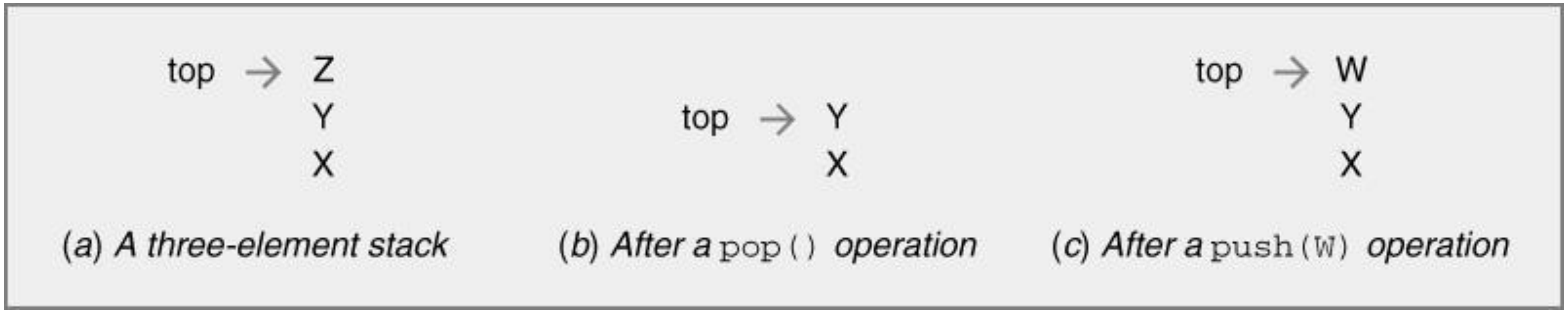
- Must update references in both predecessor and successor nodes

Restricted Abstractions

- Restricting the operations an abstraction supports can be a good thing
  - Efficiently supporting only a few operations efficiently is easier
  - If limited abstraction is sufficient, easier to reason about limited abstraction than a more general one
- Restricted list abstractions
  - **Stack** (aka LIFO queue)
  - **Queue** (aka FIFO queue)
  - **Dequeue** (aka double ended queue)

Stack

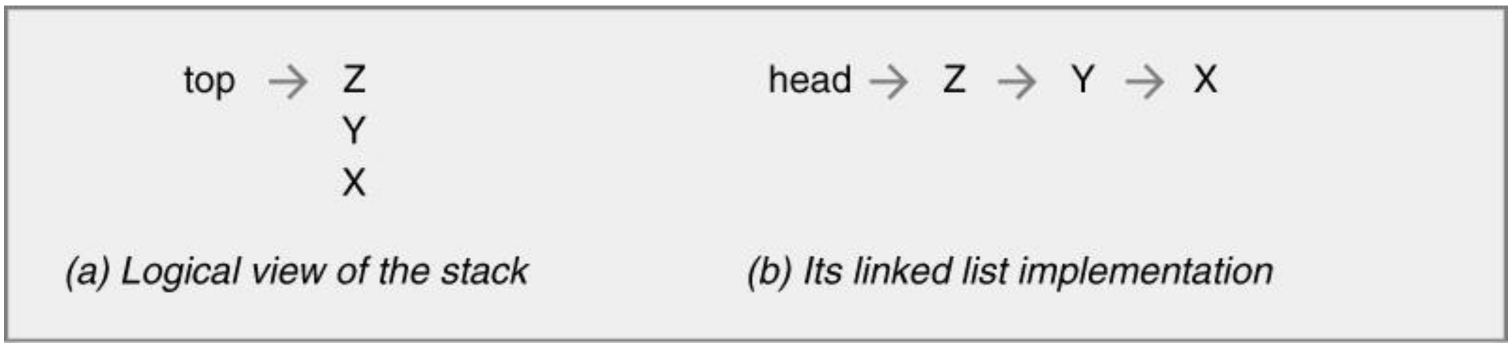
- Properties
  - Elements removed in opposite order of insertion
  - Last-in, First-out (LIFO)
- A restricted list where
  - Access only to elements at one end
  - Can add / remove elements only at one end
- Stack operations
  - Push = add element (to top)
  - Pop = remove element (from top)



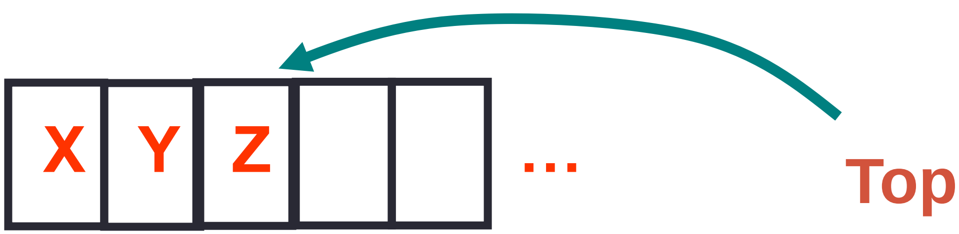
(a) *A three-element stack* (b) *After a* `pop()` *operation* (c) *After a* `push(W)` *operation*

Stack Implementations

- Linked list
  - Add / remove from head of list

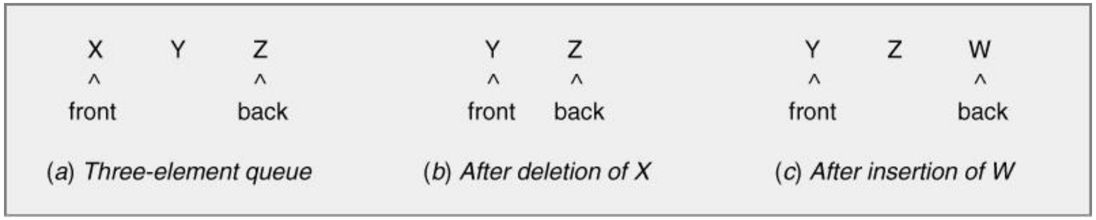


- Array
  - Increment / decrement Top pointer after push / pop



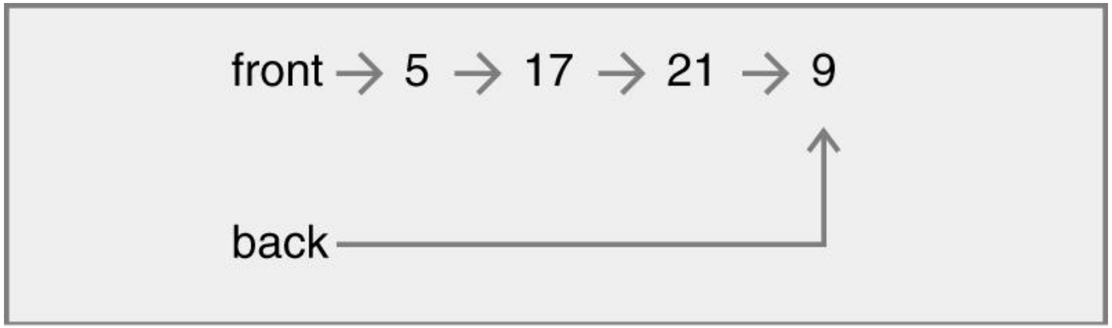
Queue

- Properties
  - Elements removed in order of insertion
  - First-in, First-out (FIFO)
- A restricted list where
  - Access only to elements at beginning / end of list
    - Add elements only to end of list
    - Remove elements only from front of list
  - Alternatively, can add to front & remove from end
- Queue operations
  - Enqueue = add element (to back)
  - Dequeue = remove element (from front)
- **Example**



Queue Implementations

- Linked list
  - Add to tail (back) of list
  - Remove from head (front) of list



- Circular array

Queue – Circular Array Implementation

- Inherent problem for queue of size N
  - Only N possible (Front – Back) pointer locations
  - N+1 possible queue configurations
    - Queue with 0, 1, … N elements
- Solutions
  - Maintain additional state information
    - Use state to recognize empty / full queue
    - Examples
      - Record Size
      - Record QueueEmpty flag
  - Leave empty element in queue
  - Store marker in queue