CMSC 132:
Object-Oriented Programming II

Linear Data Structures

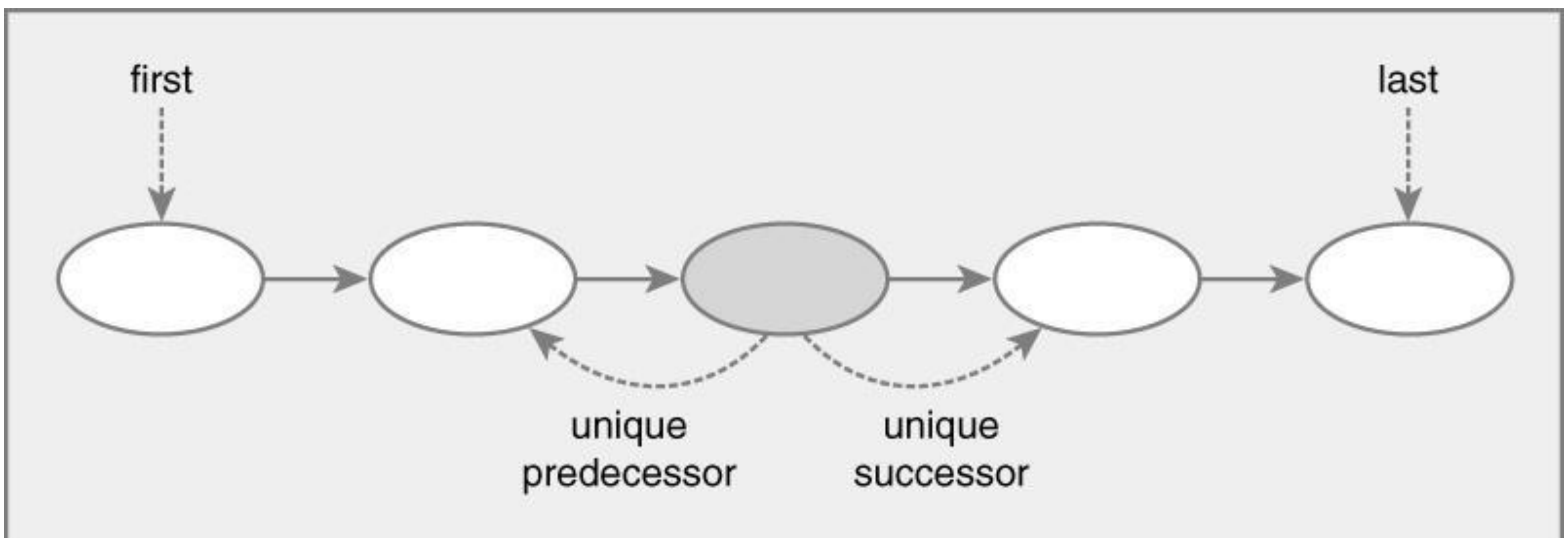
Department of Computer Science
University of Maryland, College Park

Overview

- Linear data structures
  - General properties
- Implementations
  - Array
  - Linked list
- Restricted abstractions
  - Stack
  - Queue

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**



Linear Data Structures

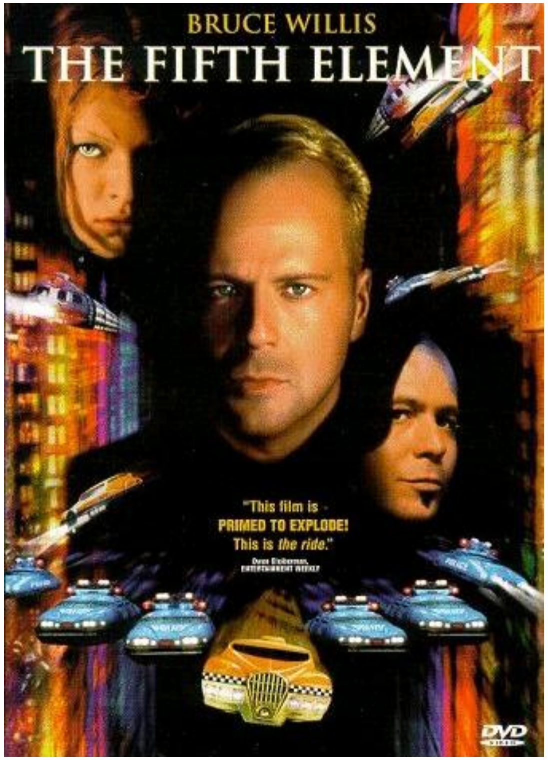
- Terminology
  - Head (first element in list) $\Rightarrow$ no predecessor
  - Tail (last element in list) $\Rightarrow$ no successor
- Operations
  - Add element
  - Remove element
  - Find element

Add & Remove Elements

- Add an element
  - Where?
    - At head (front) of list
    - At tail (end) of list
    - After a particular element
- Remove an element
  - Remove first element
  - Remove last element
  - Remove a particular element (e.g., String “Happy”)
    - What if “Happy” occurs more than once in list?

Accessing Elements

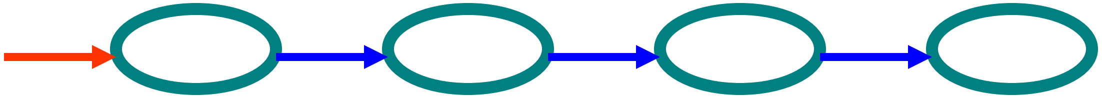
- How do you find an element?
  - At head (front) of list
  - At tail (end) of list
  - By position
    - Example: the 5th element
  - By iterating through the list, and using relative position
    - Next element (successor)
    - Previous element (predecessor)



List Implementations

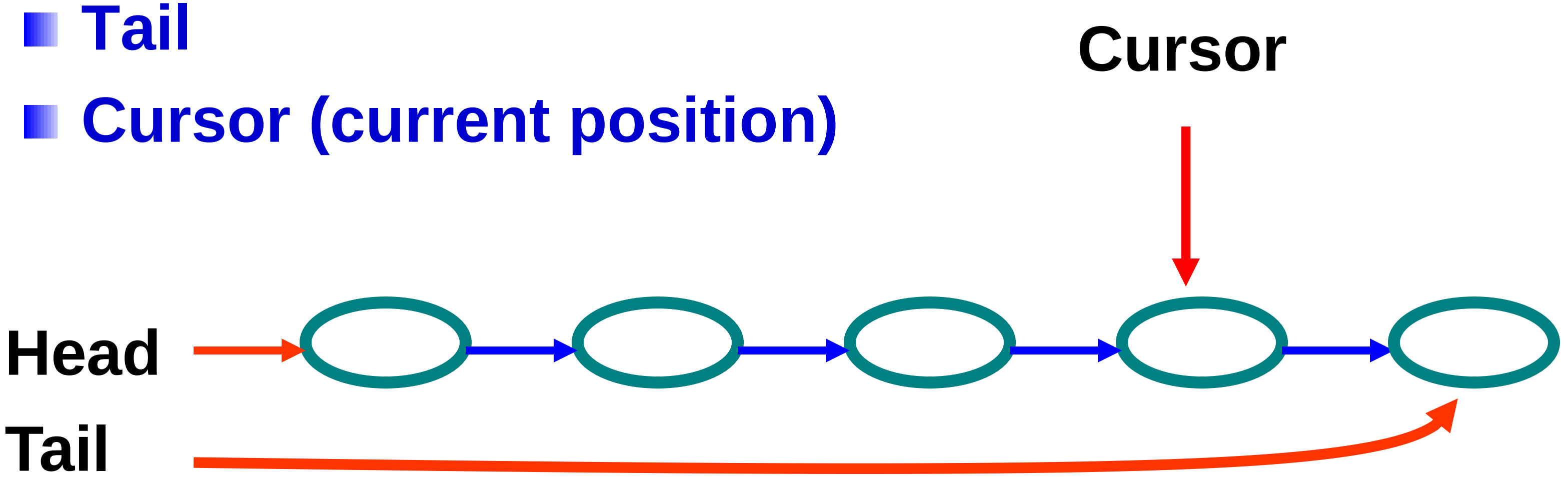
- **Two basic implementation techniques for lists**
  - **Store elements in an array**

  - **Store as a linked list**
    - **Place each element in a separate object (node)**
    - **Node contains reference to other node(s)**
    - **Link nodes together**



Linked List

- **Properties**
  - **Elements in linked list are ordered**
  - **Element has successor**
- **State of List**
  - **Head**
  - **Tail**
  - **Cursor (current position)**



Array Implementations

- Advantages
  - Can efficiently access element at any position
  - Efficient use of space
    - Space 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
  - Tricky to insert / remove elements at both ends

Linked Implementation

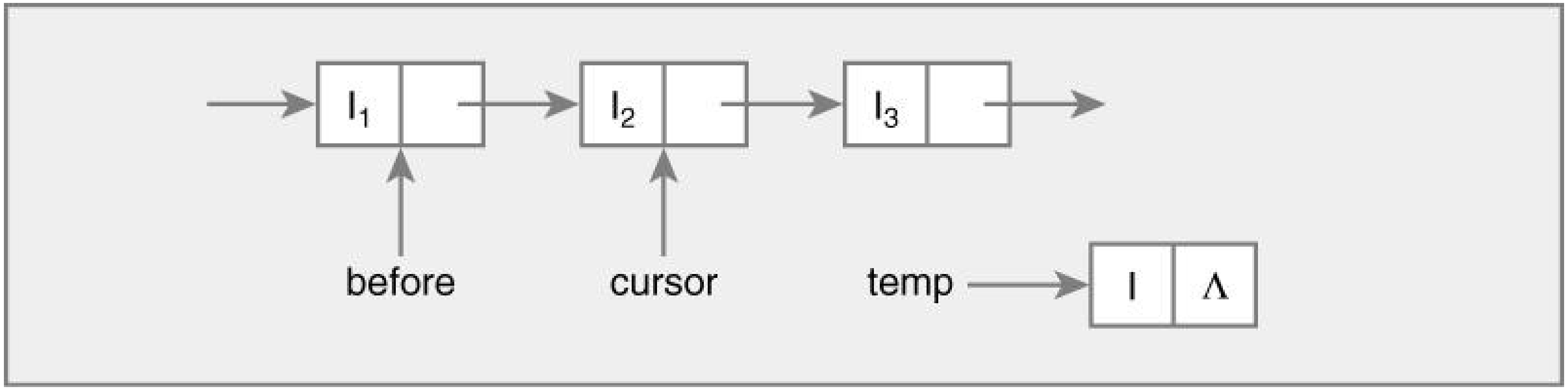
- **Advantages**
  - **Can efficiently insert / remove elements anywhere**
- **Disadvantages**
  - **Cannot efficiently access element at any position**
    - **Need to traverse list to find element**
  - **Less efficient use of space**
    - **1-2 additional references per element**

Efficiency of Operations

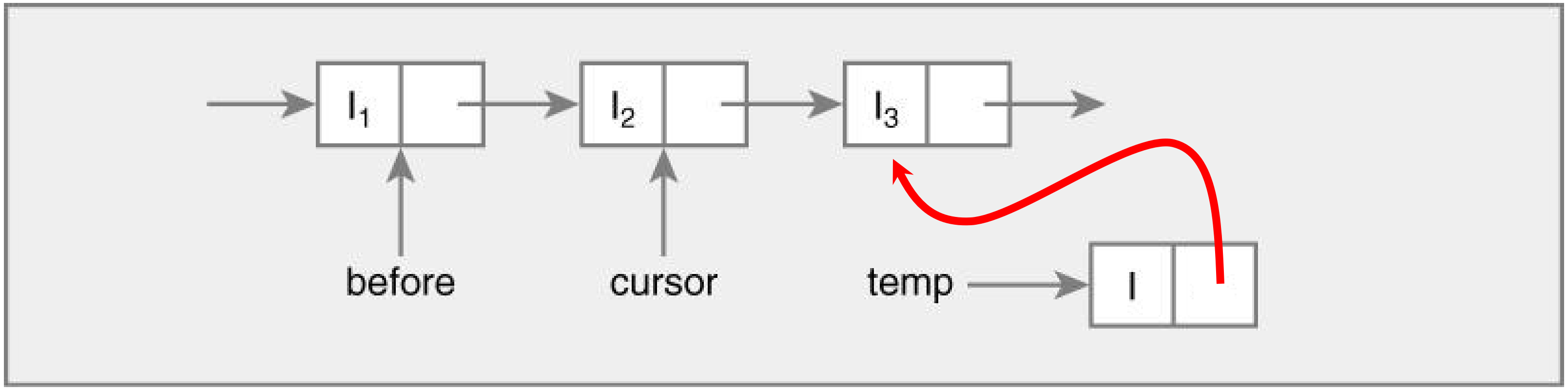
- Array
  - Insertion / deletion = O(n)
  - Indexing = O(1)
- Linked list
  - Insertion / deletion = O(1)
  - Indexing = O(n)

Linked List – Insert (After Cursor)

1. **Original list & new element temp**

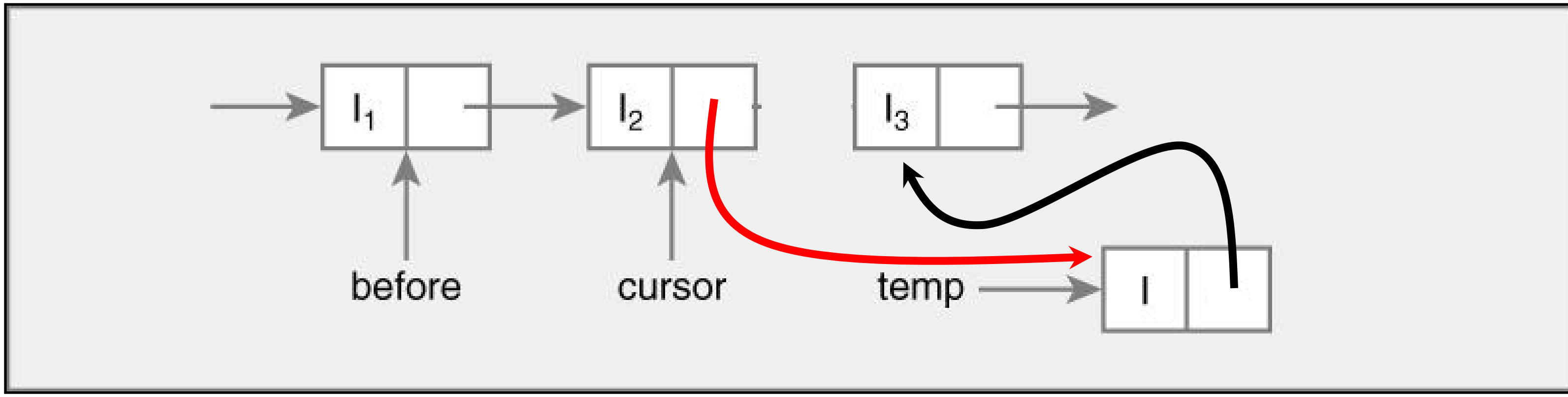


2. **Modify temp.next → cursor.next**

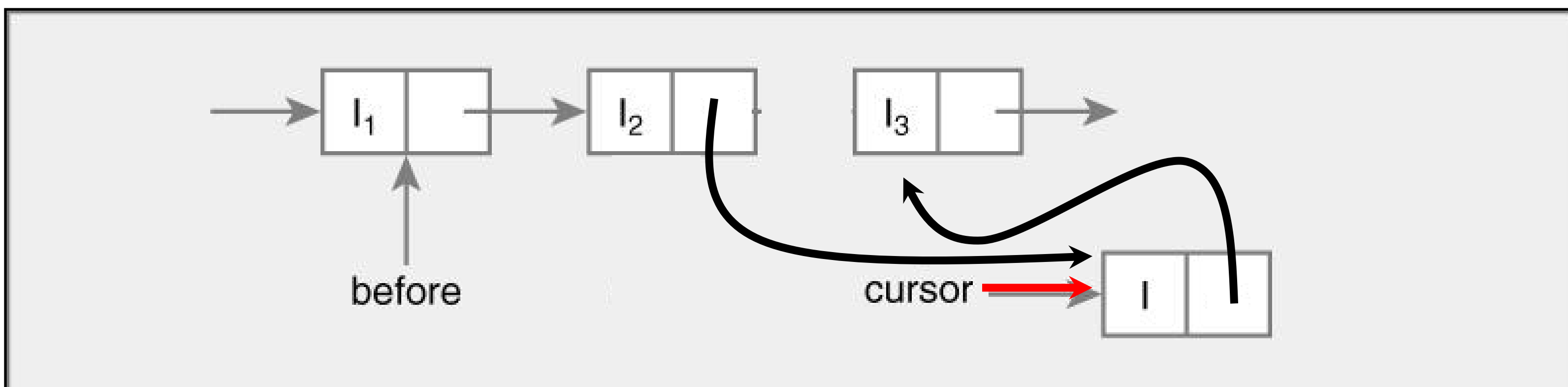


Linked List – Insert (After Cursor)

3. Modify cursor.next → temp

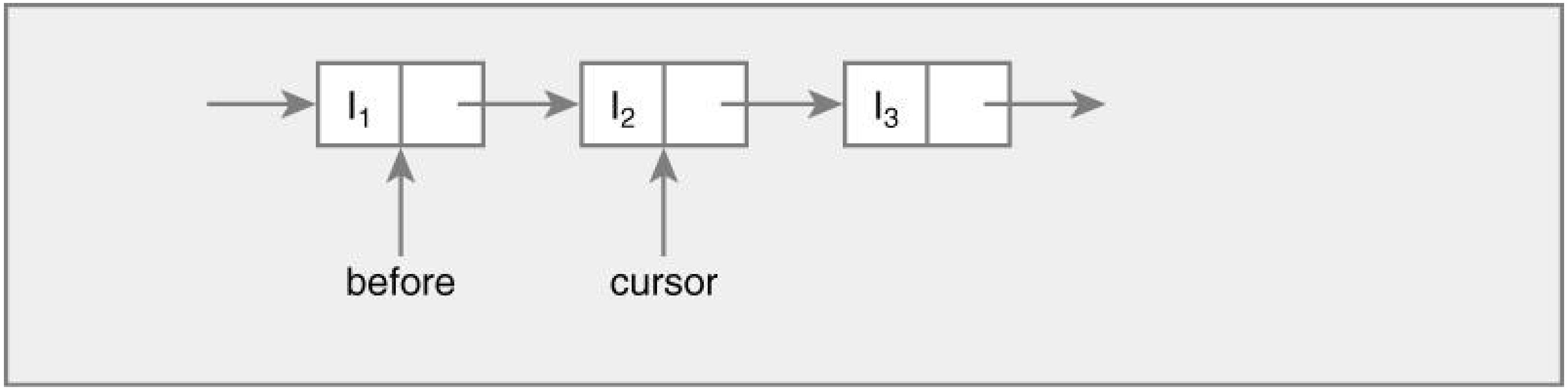


4. Modify cursor → temp

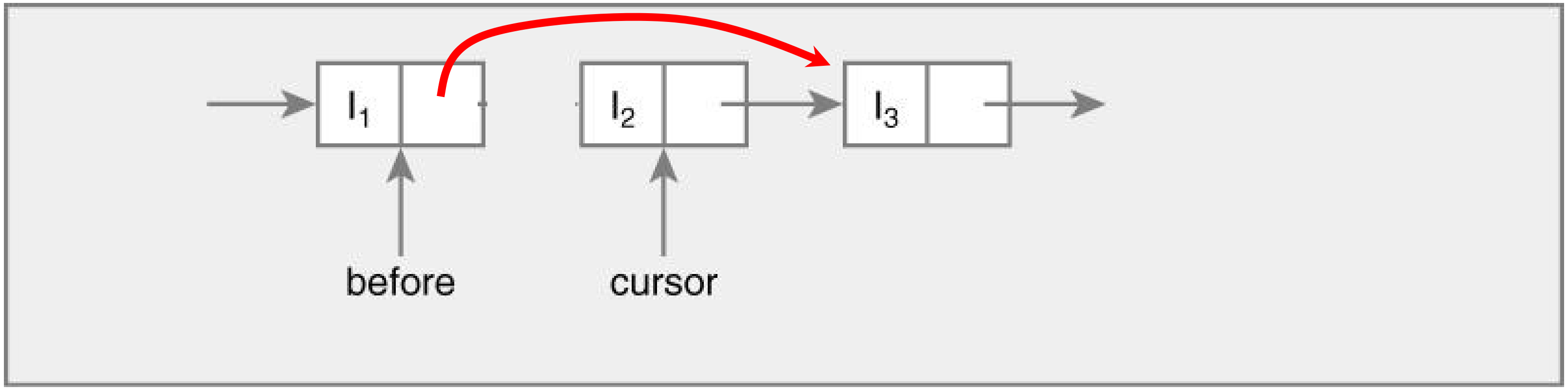


Linked List – Delete (Cursor)

1. **Find before such that before.next = cursor**

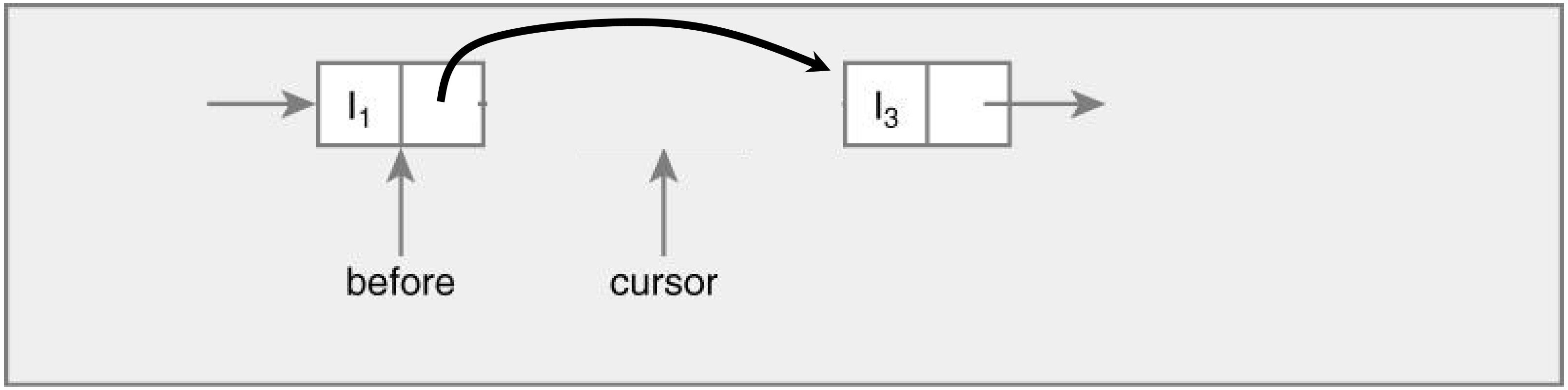


2. **Modify before.next → cursor.next**

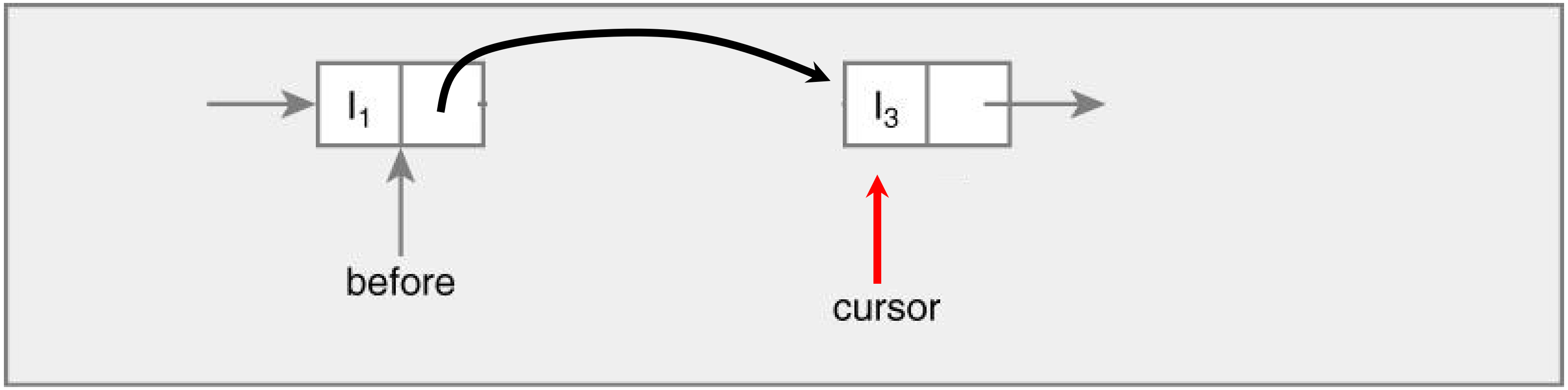


Linked List – Delete (Cursor)

3. Delete cursor

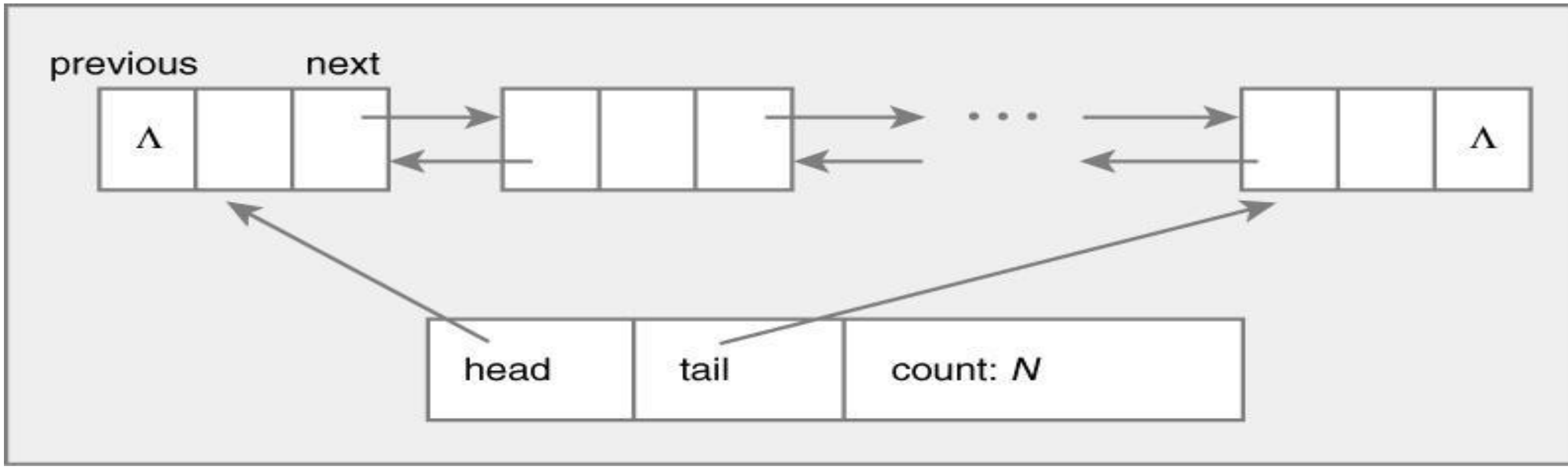


4. Modify cursor → before.next



Doubly Linked List

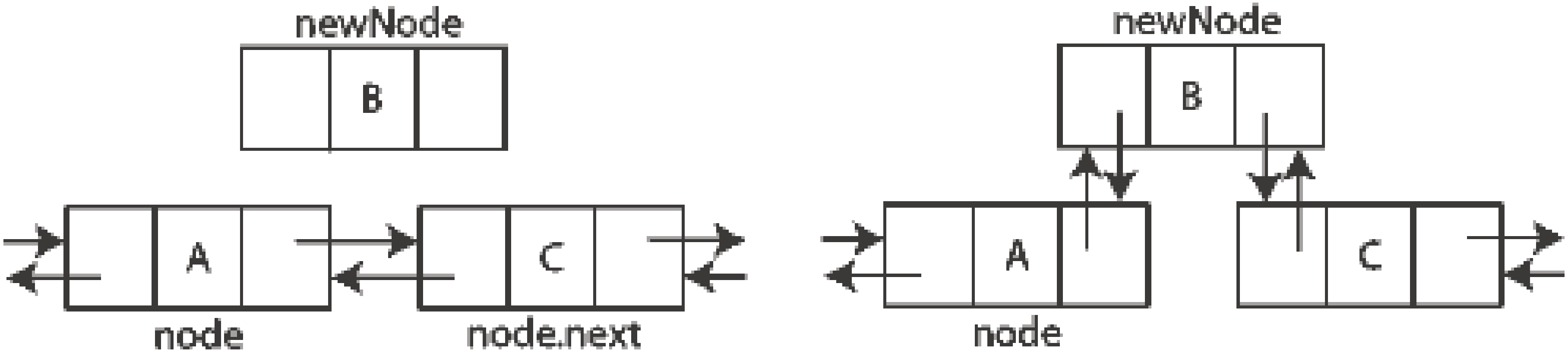
- **Linked list where**
  - **Element has predecessor & successor**



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

Doubly Linked List – Insertion

- **Example**

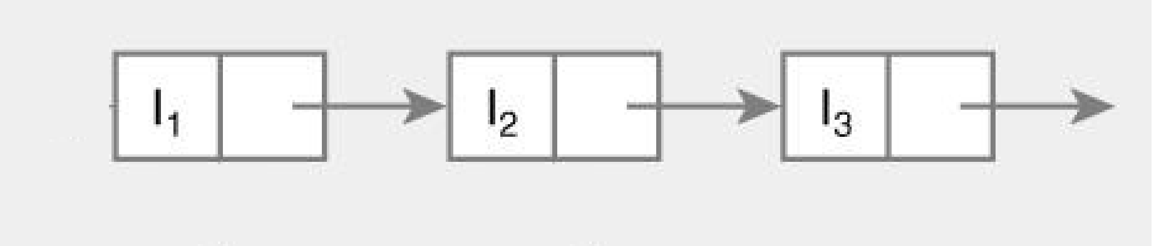


- **Must update references in both predecessor and successor nodes**

Node Structures for Linked Lists

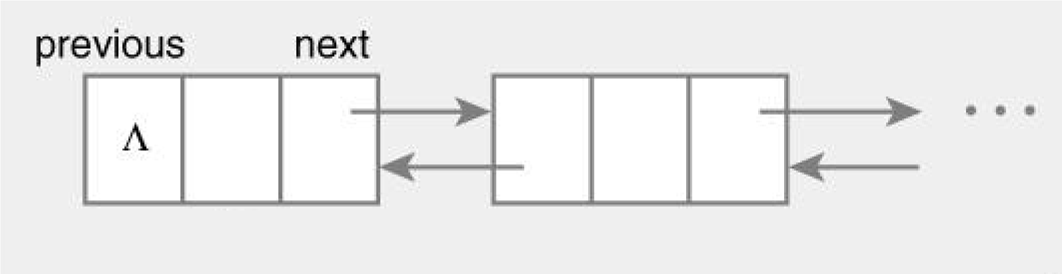
- **Linked list**

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



- **Doubly linked list**

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



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

- **Stack operations**
  - **Push = add element (to top)**
  - **Pop = remove element (from top)**
- **Example**

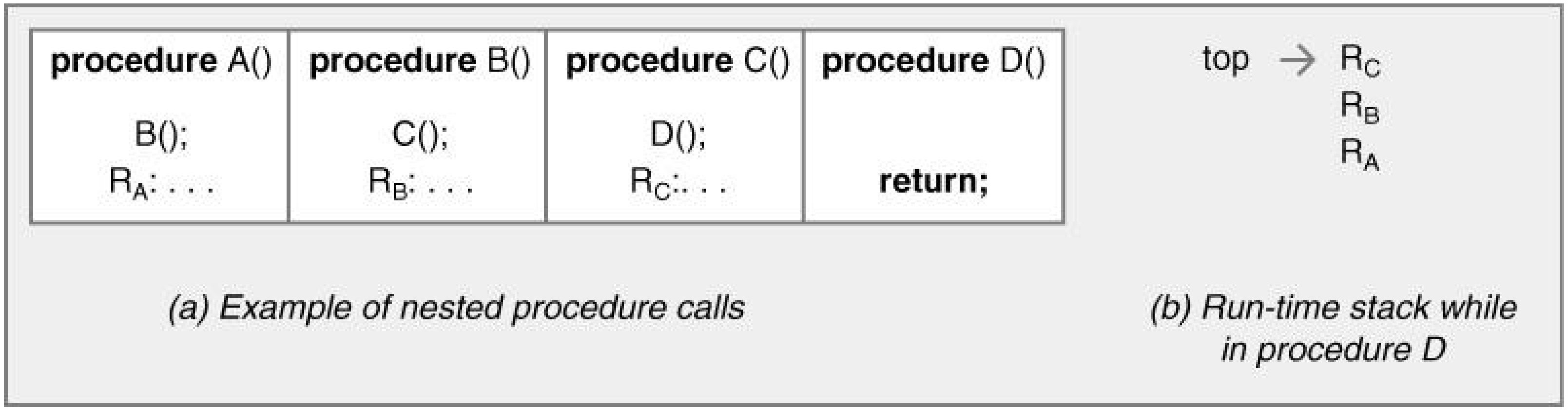
(*a*) *A three-element stack* (*b*) *After a* `pop()` *operation* (*c*) *After a* `push(W)` *operation*

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 Applications

- **Run-time procedure information**



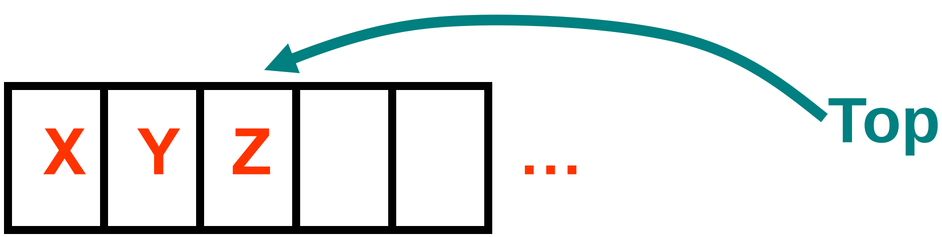
- **Arithmetic computations**
  - **Postfix notation**
- **Simplified instruction set**
  - **Java bytecode**

Stack Implementations

- **Linked list**
  - **Add / remove from head of list**

(a) Logical view of the stack *(b) Its linked list implementation*

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



Queue

- **Queue operations**
  - **Enqueue = add element (to back)**
  - **Dequeue = remove element (from front)**

- **Example**

```
X     Y     Z               Y     Z                   Y     Z     W
^           ^               ^     ^                   ^           ^
front       back            front back                front       back
```

(*a*) *Three-element queue* (*b*) *After deletion of X* (*c*) *After insertion of W*

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

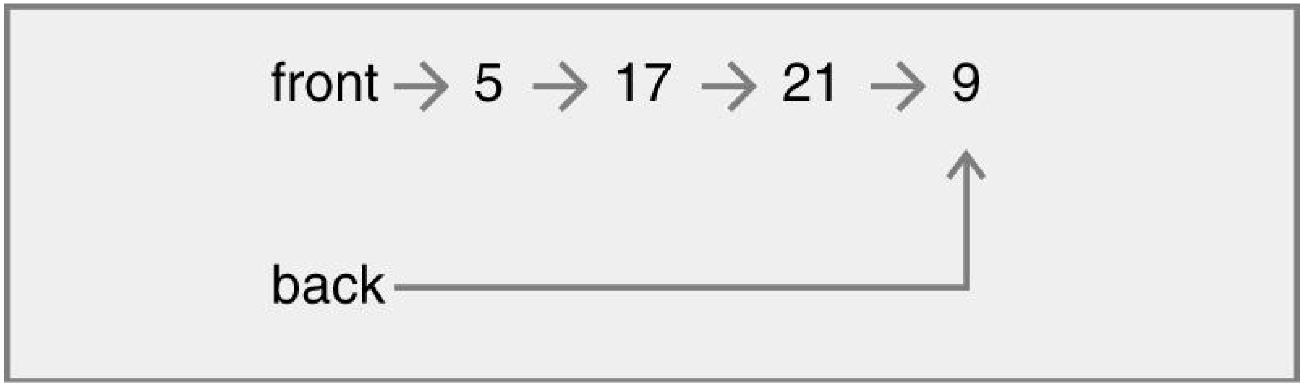
Queue Applications

- **Examples**
  - **Songs to be played**
  - **Jobs to be printed**
  - **Customers to be served**
  - **Citizens to cast votes**

South Africa, 2004

Queue Implementations

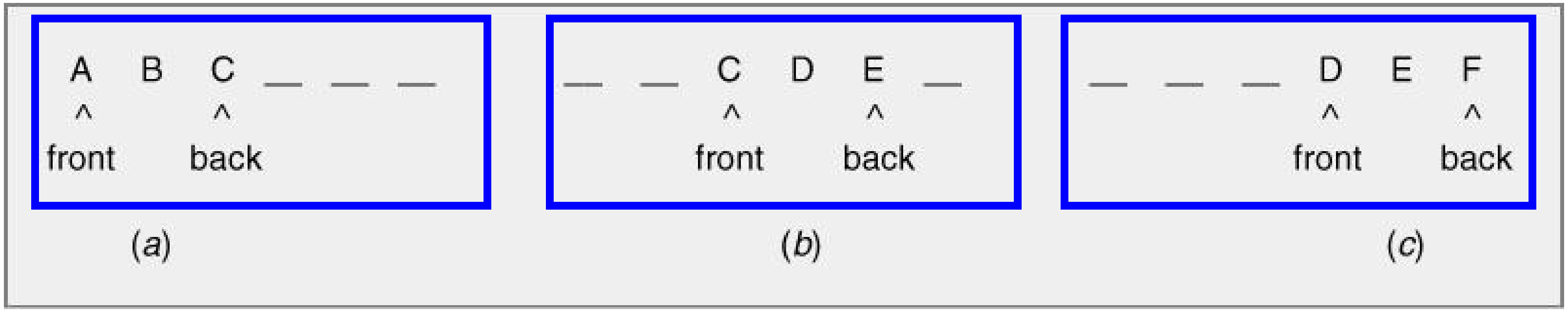
- **Linked list**
  - **Add to tail (back) of list**
  - **Remove from head (front) of list**



- **Array**
- **Circular array**

Queue – Array

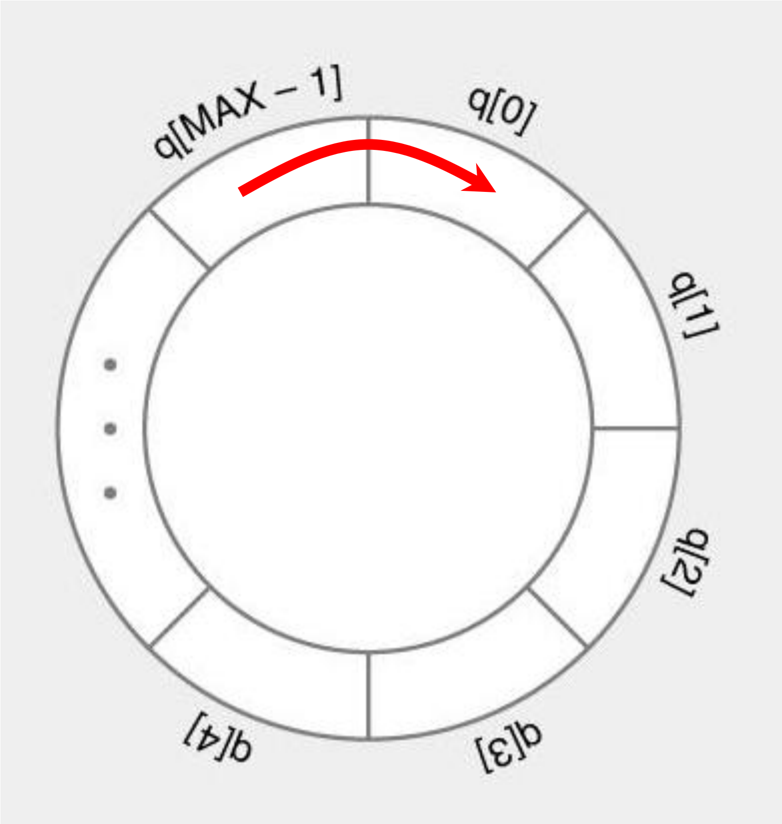
- **Store queue as elements in array**
- **Problem**
  - **Queue contents move ("inchworm effect")**



  - **As result, can not add to back of queue, even though queue is not full**

Queue – Circular Array

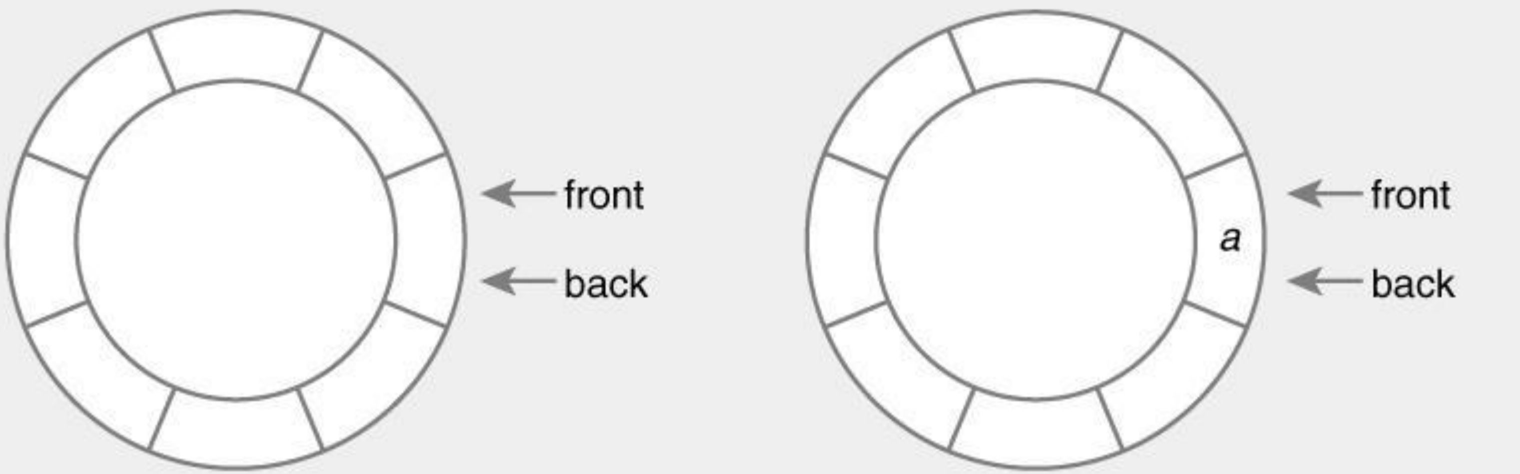
- **Circular array (ring)**
  - **q[0] follows q[MAX – 1]**
  - **Index using q[i % MAX]**



- **Problem**
  - **Detecting difference between empty and nonempty queue**

Queue – Circular Array

- **Approach 1**
  - **Keep Front at first in**
  - **Keep Back at last in**



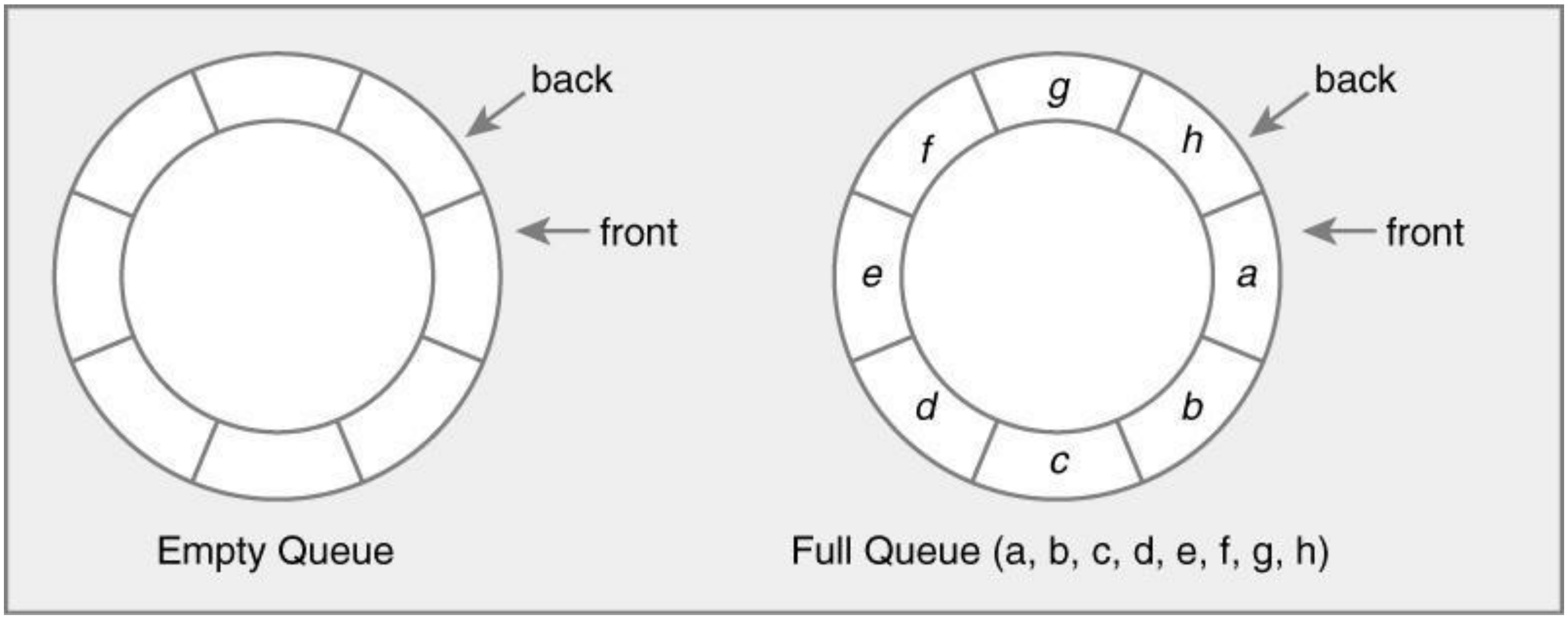
Empty Queue

Queue with One Element a

- **Problem**
  - **Empty queue identical to queue with 1 element**

Queue – Circular Array

- **Approach 2**
  - **Keep Front at first in**
  - **Keep Back at last in – 1**



- **Problem**
  - **Empty queue identical to full queue**

Queue – Circular Array

- **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**