CMSC 132:
Object-Oriented Programming II

Linear Data Structures

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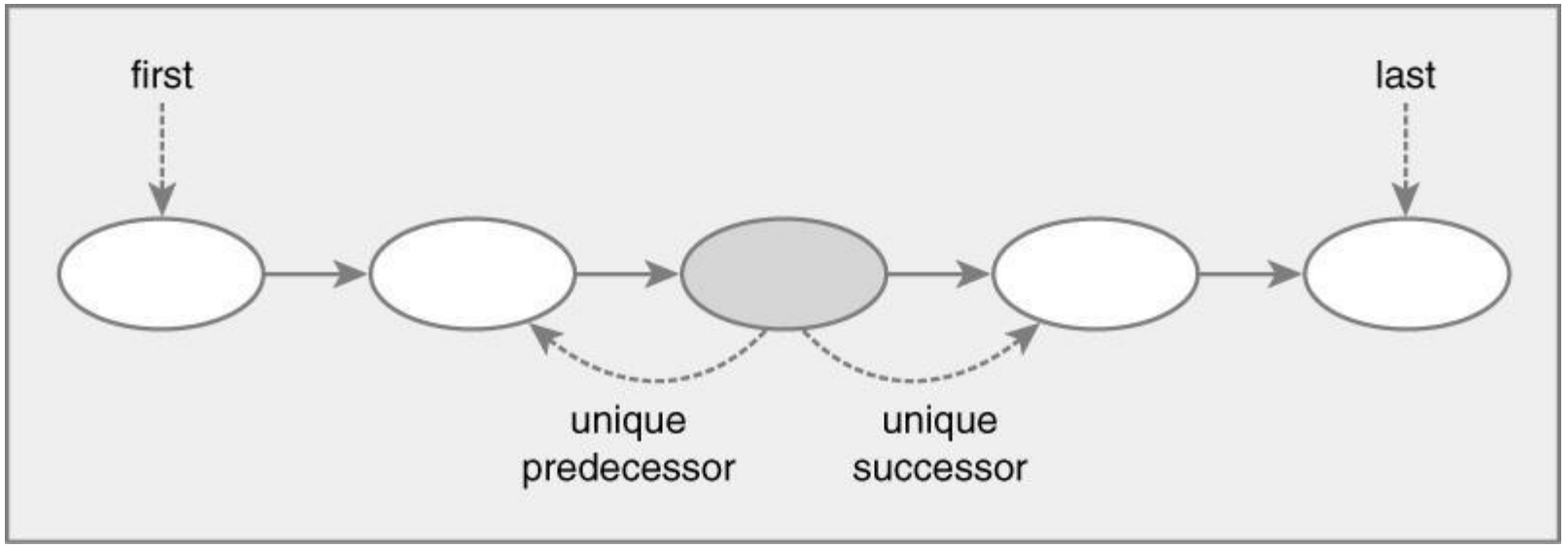
Overview

- 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) ⇒ no predecessor**
  - **Tail (last element in list) ⇒ no successor**

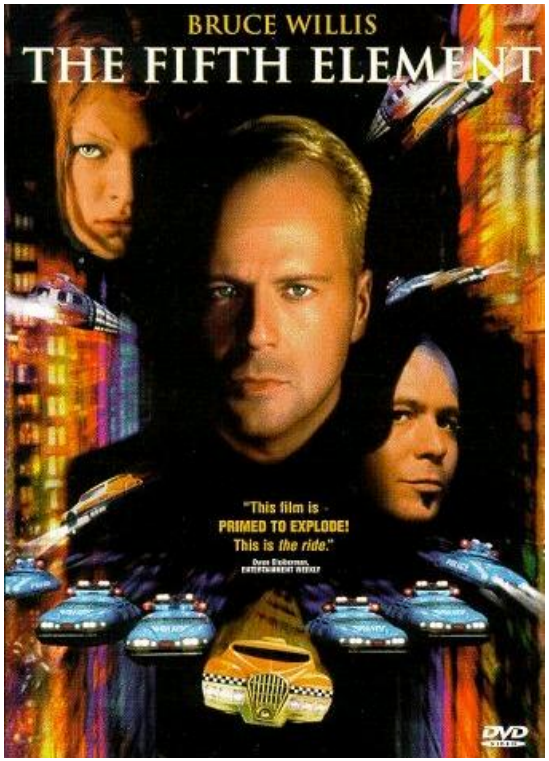
- **Operations**
  - **Add element**
  - **Remove element**
  - **Find element**

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

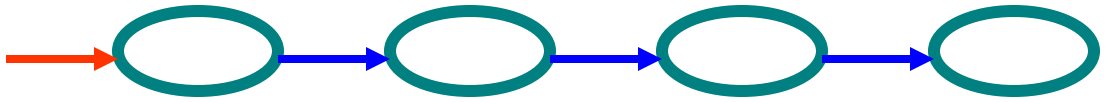
- How do you find an element?
  - At head (front) of list
  - At tail (end) of list
  - By position
    - Example: the 5th element
  - By iterating through the list, and using relative position
    - Next element (successor)
    - Previous element (predecessor)



List Implementations

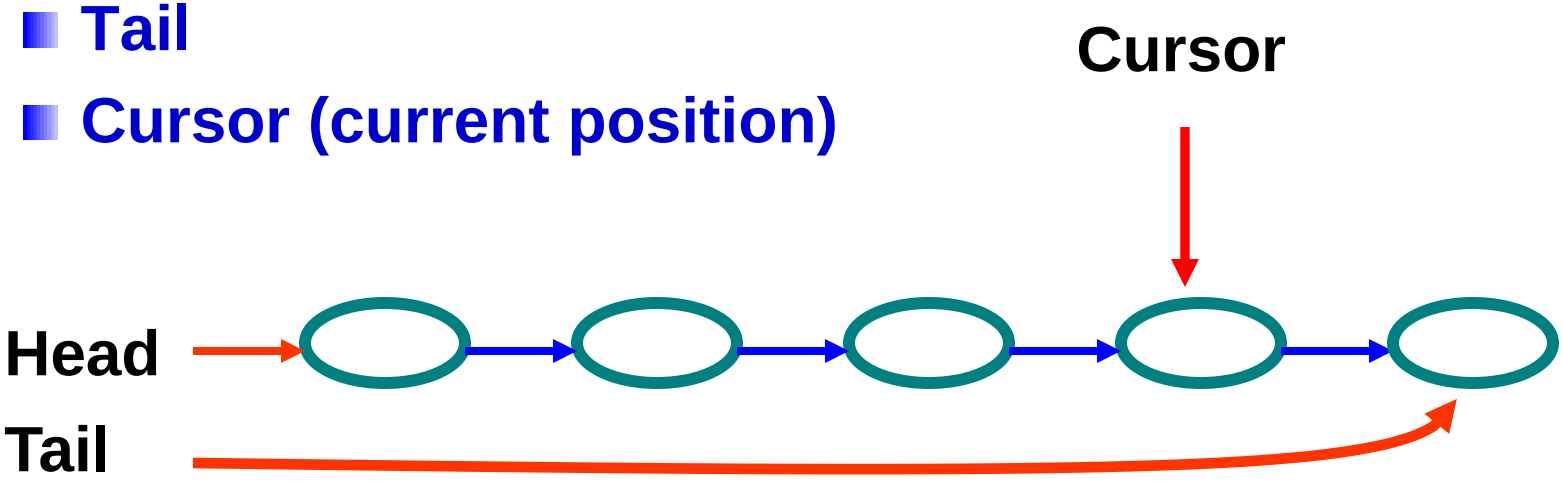
- **Two basic implementation techniques for lists**
  - **Store elements in an array ("Sequential Allocation")**

  - **Store as a linked list ("Linked Allocation")**
    - **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

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

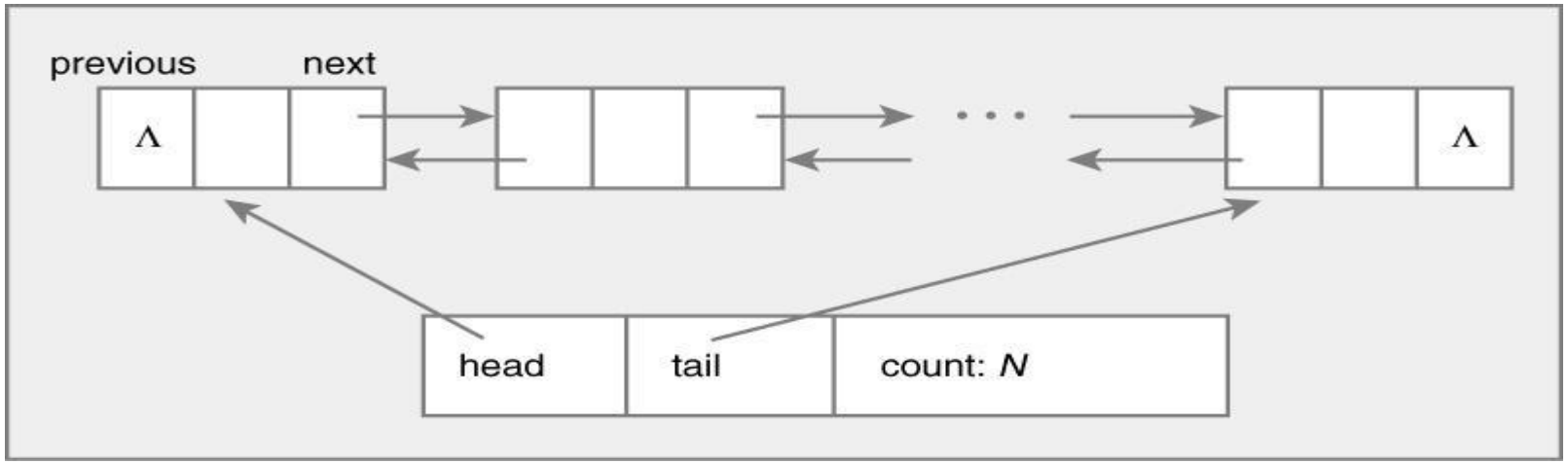
- **Array**
  - **Insertion / deletion = O(n)**
  - **Indexing = O(1)**
- **Linked list**
  - **Insertion / deletion = O(1)**
  - **Indexing = O(n)**

Linked List Example

- **Coding Example of LinkedList**

Doubly Linked List

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

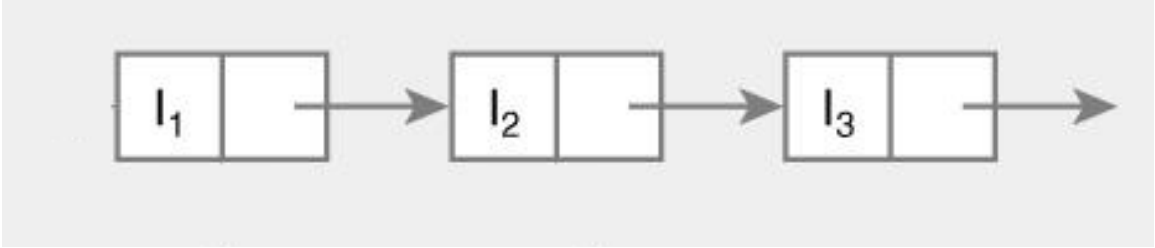


- **Issues**
  - **Easy to find preceding / succeeding elements**
  - **Extra work to maintain links (for insert / delete)**
  - **More storage per node**

Node Structures for Linked Lists

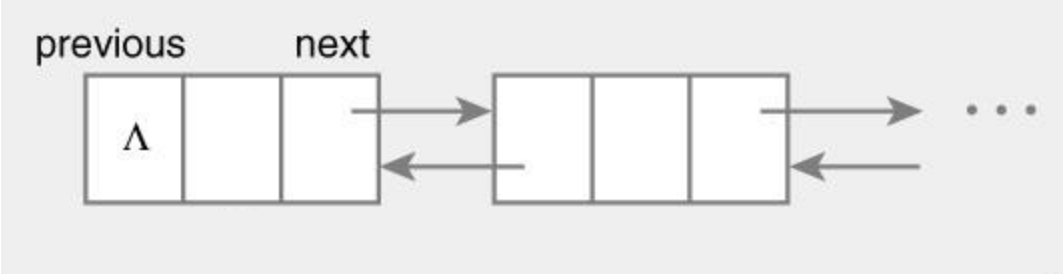
- **Linked list**

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



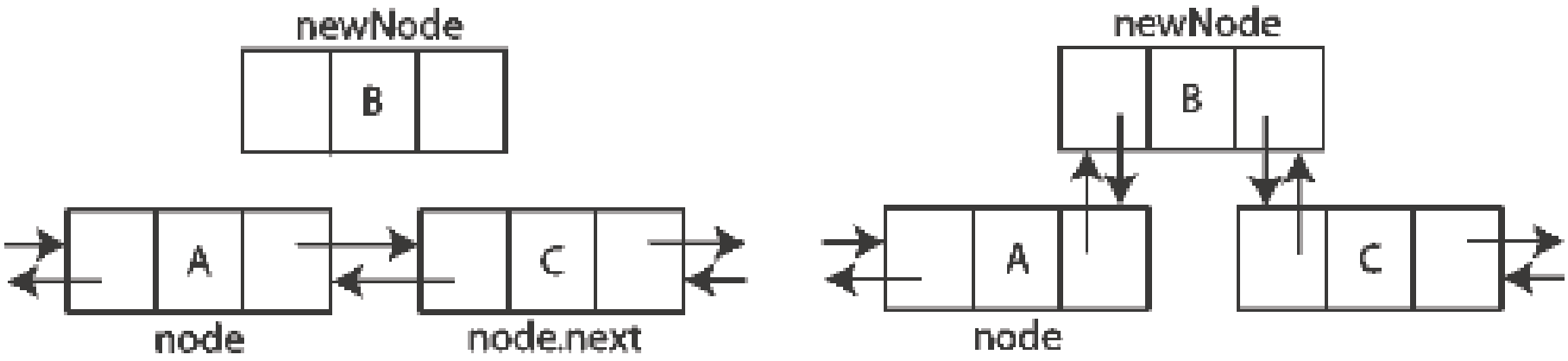
- **Doubly linked list**

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



Doubly Linked List – Insertion

- **Example**



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

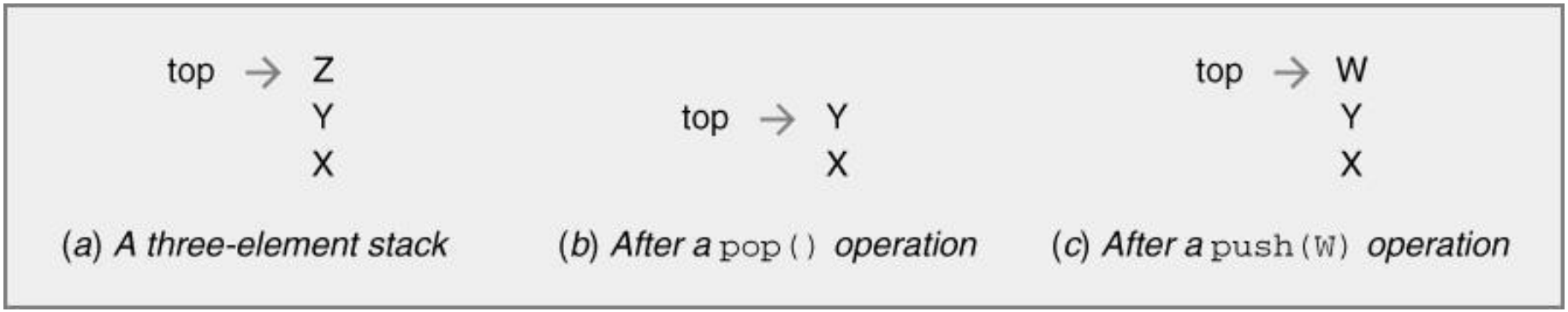
Stack

- **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

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

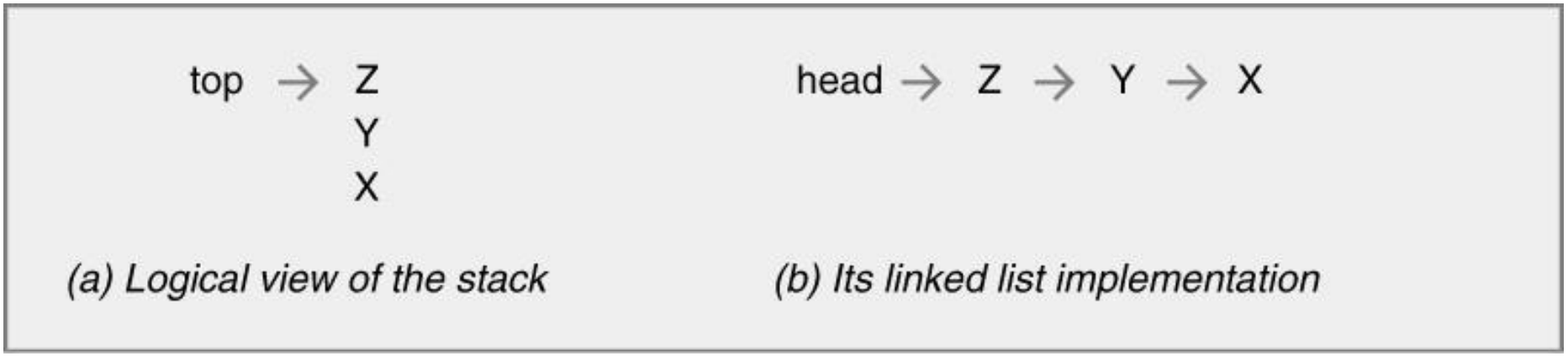
- **Example**



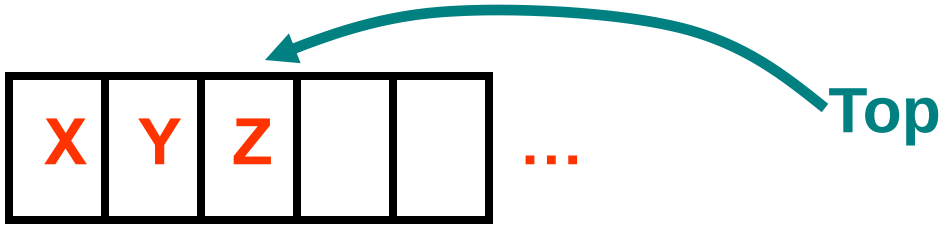
(a) *A three-element stack* (b) *After a* `pop()` *operation* (c) *After a* `push(W)` *operation*

Stack Implementations

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



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



Queue

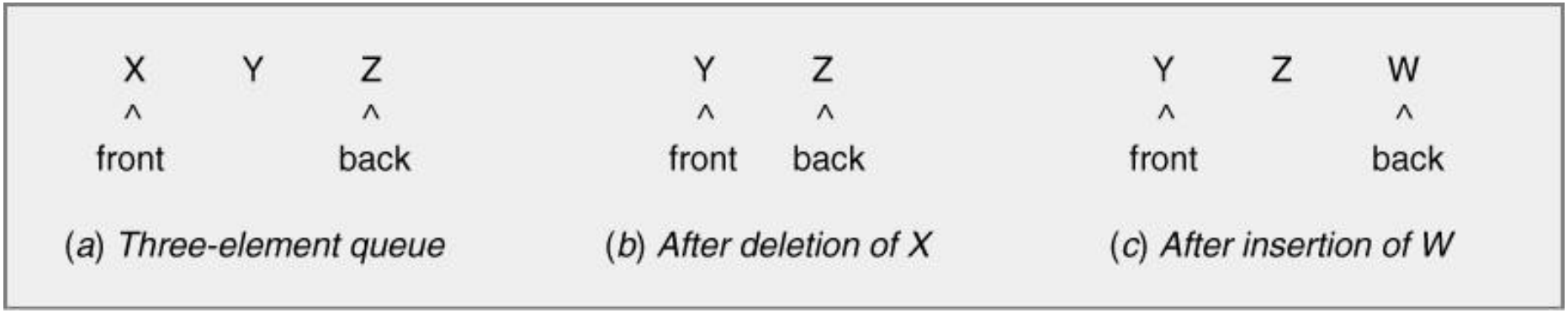
- **Properties**
  - **Elements removed in order of insertion**
  - **First-in, First-out (FIFO)**

- **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

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

- **Example**



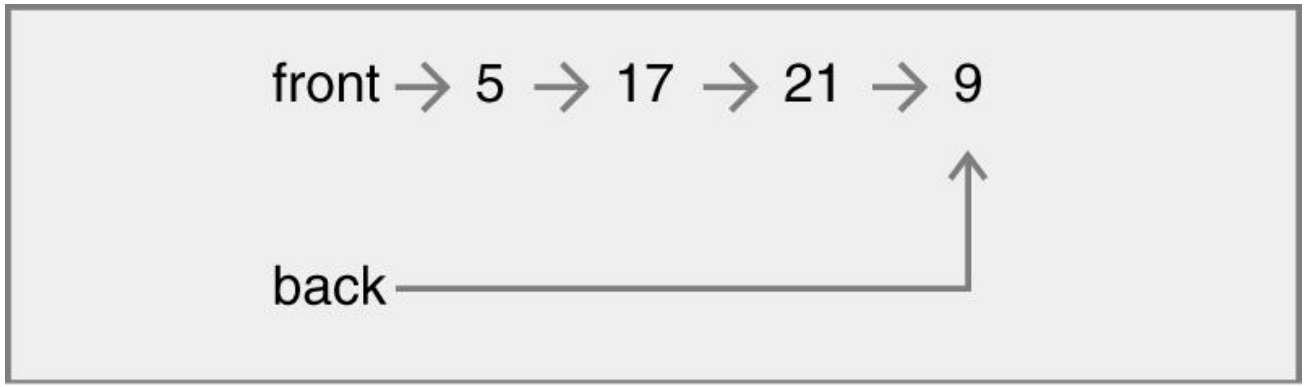
Queue Applications

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

South Africa, 2004 →

Queue Implementations

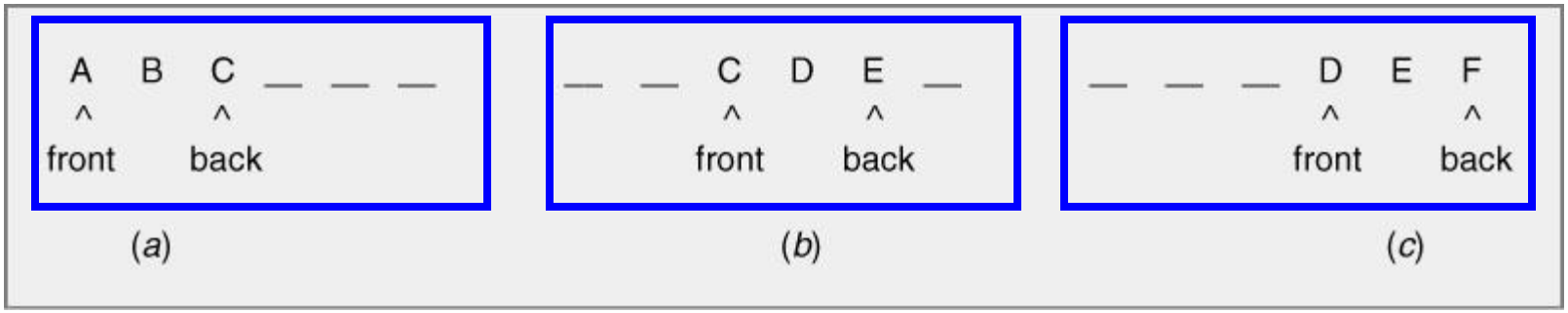
- **Linked list**
  - **Add to tail (back) of list**
  - **Remove from head (front) of list**



- **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**