CMSC 132:
OBJECT-ORIENTED PROGRAMMING II

Linear Data Structures

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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

```java
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`

```
I_1 ➔ I_2 ➔ I_3
```

2. Modify `temp.next` → `cursor.next`
Linked List – Insert (After Cursor)

3. Modify \texttt{cursor.next} \rightarrow \texttt{temp}

4. Modify \texttt{cursor} \rightarrow \texttt{temp}
Linked List – Delete (Cursor)

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

   ![Diagram 1]

2. Modify `before.next → cursor.next` 

   ![Diagram 2]
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

```
top  →  Z
Y
X
```

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

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

```
X  Y  Z [...]
```

Top
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

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>^</td>
<td>^</td>
<td>^</td>
</tr>
<tr>
<td>front</td>
<td>back</td>
<td>front</td>
</tr>
</tbody>
</table>

  (a) Three-element queue

<table>
<thead>
<tr>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>^</td>
<td>^</td>
</tr>
<tr>
<td>front</td>
<td>back</td>
</tr>
</tbody>
</table>

  (b) After deletion of X

<table>
<thead>
<tr>
<th>Y</th>
<th>Z</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>^</td>
<td>^</td>
<td>^</td>
</tr>
<tr>
<td>front</td>
<td>back</td>
<td>front</td>
</tr>
</tbody>
</table>

  (c) After insertion of W
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