Linear Data Structures

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Announcements

• Make sure you verify what you submit for Project #3.
• Regarding CS Staff
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

```
before   cursor   temp → temp
| l1 | l2 | l3 |
```

2. Modify temp.next → cursor.next

```
before   cursor   temp → cursor
| l1 | l2 | l3 |
```
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)
  - **Deque** (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 $\rightarrow$ add element (to top)
  - Pop $\rightarrow$ remove element (from top)

\[\begin{array}{c}
top \rightarrow Z \\
| Y \\
| X \\
\end{array} \quad \begin{array}{c}
top \rightarrow Y \\
| X \\
\end{array} \quad \begin{array}{c}
top \rightarrow W \\
| Y \\
| X \\
\end{array}\]

(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

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

(a) Three-element queue   (b) After deletion of X   (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 \text{ flag}
  • Leave empty element in queue
  • Store marker in queue