Closed Lists
and
Related Data Structures

Open vs. Closed Lists

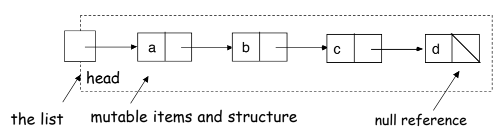
- Two list models are described in the text:
  - **Open lists:**
    - Elements and sublists can be shared
    - Mutation of lists is discouraged
    - Use without side-effects, functional programming
    - Mathematically elegant
  - **Closed lists:**
    - Sharing generally not done
    - Mutation of lists is ok, because they are encapsulated
    - Use with side-effects, object-oriented programming
    - Mathematically more cumbersome
  - Closed lists can be built by **wrapping** open lists

Purpose of Closed Lists

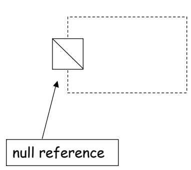
- A closed list is used for its **identity and state** as an **object**, rather than purely for its **value** as a sequence.
- Several "clients" can access the same closed list; modifications made by one will be felt by all.
- In some cases, this is the desired behavior.
- More space-efficient, for *some* applications, due to in-place modification.

Closed List Implementation

- A closed list can be viewed as a "list in a box".
- Cells in the list are typically **not shared** from the outside, so they can be **mutated** at will.
- Outside access is through a mutable reference called the "**head**".



An Empty Closed List



Possible Java implementation which we won't use

```
import OpenList;

class ClosedList
{
private OpenList head;

OpenList() { }

        . . . other stuff . . .

}
```

How to Add and Remove Elements?

- To add, must specify:
  - Item to be added
  - To where it should be added
- To remove, must specify
  - From where it should be removed

Some Typical Choices

- Always add and remove from the head.
- Always add and remove from the tail.
- Add to the tail, remove from the head.
- Add and remove at random places (how to identify where?)

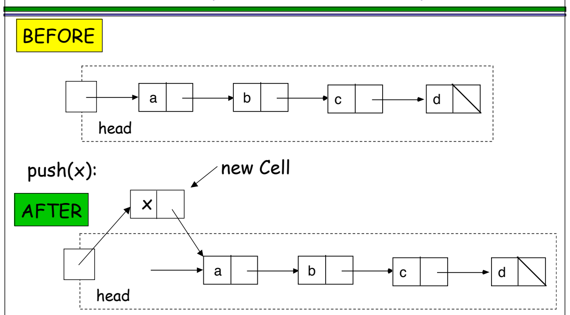
Common Closed List Usages

- **Stack**
  - remove elements in *reverse* order of entry, i.e. last-in element is first-out ("LIFO")
- **Queue**
  - remove elements in order of entry, i.e. first-in element is first-out ("FIFO")

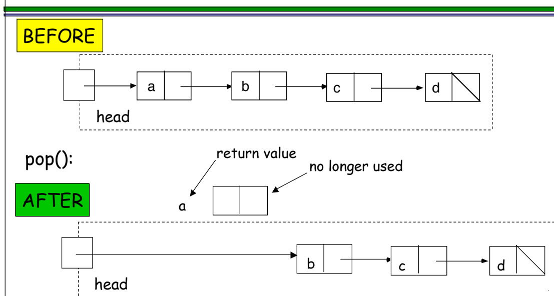
Stack Abstraction

```
Stack s = new Stack();
s.push("a");
s.push("b");
s.push("c");
value = s.pop();    // value will be "c"
value = s.pop();    // value will be "b"
value = s.pop();    // value will be "a"
```

Stack Implementation (push)

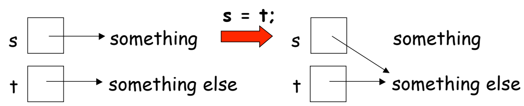


Stack Implementation (pop)



Reading Code
containing References and Pointers

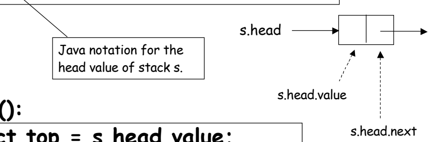
- Suppose s and t are references.
- **Read** the assignment statement
  s = t;
  as "make s point to where t points".
- To see why, consider



Figurative Code for Push/Pop

- **s.push(Object x):**

```
s.head = new Cell(x, s.head);
```



- **s.pop():**

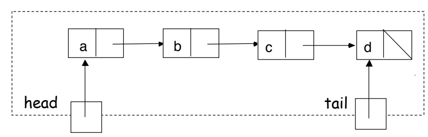
```
Object top = s.head.value;
s.head = s.head.next;
return top;
```

Queue Abstraction

```
Queue r = new Queue();
r.enqueue("a");
r.enqueue("b");
r.enqueue("c");
value = r.dequeue();    // value will be "a"
value = r.dequeue();    // value will be "b"
value = r.dequeue();    // value will be "c"
```

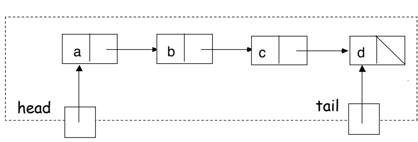
Queue Implementation

- For a queue, we usually add another reference, to the last element, for convenience.
  This element is called the **tail**.



Enqueue/Dequeue

- **enqueue** adds a new element to one end of the internal open list.
- **dequeue** removes an element and returns it.
- *But which end is used for which?*

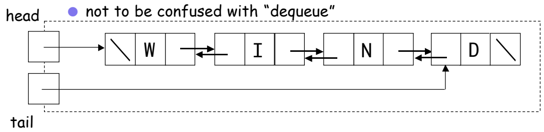


Related Topics

- **Lists of lists**: No problem with OpenList, or in any framework in which lists contain Objects and are objects.
- Otherwise, need to define special type of list, tailored to the type of element being listed.

Doubly-Linked Lists

- An **implementation** concept
- Could use to implement **double-ended queue abstraction:**
  - "deque" (pron. "deck")
  - not to be confused with "dequeue"



Deque Abstraction

- void **enqueueFront**(Object)
- Object **dequeueFront**()
- void **enqueueBack**(Object)
- Object **dequeueBack**()
- boolean **isEmpty**()

return value types

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- Define Interfaces
  - **`Queue: constructor, enqueue, dequeue, isEmpty`**
  - **`Deque : constructor, enqueueFront, dequeueBack, enqueueBack, dequeueFront, isEmpty`**
  - **`PriorityQueue (extra credit)`**
- Implement
  - **`MyQueue`**
  - **`MyDeque`**
  - **`MyPriorityQueue (extra credit)`**

PriorityQueue

- Elements must implement interface **`Comparable`**
- dequeue always removes the smallest with respect to **`compareTo`** method

General Doubly-Linked Lists

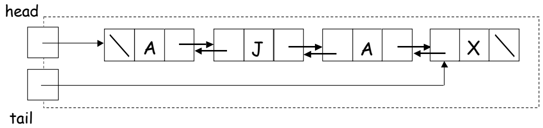
- Extend usage in Deque by allowing insertion and removal at **arbitrary** points
- Can access the object **before** any object, as well as after, unlike singly-linked lists.
- Disadvantages:
  - More storage is used for the extra pointer per cell.
  - Sharing is extremely tricky; better not to share.
- Applications?

Doubly-Linked Lists as an Implementation Concept

- In the **implementation** (as opposed to abstraction), we realize that the list is composed of cells.
- Cells make it easy to talk about various operations

Doubly-Linked Lists as an Implementation Concept

- Cells make it easy to talk about various operations:
  - **void insertAfter(cell, newCell)**
  - **void insertBefore(cell, newCell)**
  - **void remove(cell)**
  - **Cell getNext()**
  - **Cell getPrevious()**



Possible Abstractions for Doubly-Linked Lists

- A problem is that **Cell** is an ***implementation*** concept, one that **does not make an attractive *abstraction*** or user interface.
- A preferable view is to think in terms of a list **Iterator** (or **Cursor**), which maintains an **abstract position** within a list and can move backward or forward.
- The Iterator determines an **insertion point** for a new value, or point before/after a value is removed.

Example: **ListIterator** (in java.util)

- If **L** is a List, then **L.listIterator()** returns a **ListIterator** positioned at the start of the list.
- For a **ListIterator**:
  - **Object next()** returns the next element, if any
  - **boolean hasNext()** tells whether there is a next element
  - **Object previous()** returns the previous element, if any
  - **boolean hasPrevious()** tells whether there is a previous element
  - **void set(Object)** sets the value at the current position
  - **void remove()** removes the value at the current position
  - **void add(Object)** adds a value at the current position

Example, part 1

(complete source file)

```
import java.util.*;

class TestListIterator
{
public static void main(String arg[])
  {
  LinkedList ll = new LinkedList();    // create a LinkedList

  ll.add("north");                      // add some elements
  ll.add("east");
  ll.add("south");
  ll.add("west");
  System.out.println(ll);

  ll.add(1, "northeast");               // add at position 1 of ll
  ll.addLast("northwest");
  System.out.println(ll);
```

output so far:

```
[north, east, south, west]
[north, northeast, east, south, west, northwest]
```

Example (cont'd)

```
ListIterator it = ll.listIterator();  // get a new iterator for ll
it.next();                            // move the iterator
it.next();
it.next();
it.add("southeast");                  // add another element
System.out.println(ll);

while( it.hasNext() )                 // move to end
  {
  it.next();
  }

it.previous();                        // move back
it.previous();
it.add("southwest");                  // add another element
System.out.println(ll);
```

additional output:

```
[north, northeast, east, southeast, south, west, northwest]
[north, northeast, east, southeast, south, southwest, west, northwest]
```

Example (cont'd)

```
 while( it.hasPrevious() )              // move to start
   {
   it.previous();
   }

  it.next();
  it.next();
  it.remove();                           // remove element
  System.out.println(ll);

  it.add("northeast");                   // insert
  System.out.println(ll);
  }

}
```

final output:

```
[north, east, southeast, south, southwest, west, northwest]
[north, northeast, east, southeast, south, southwest, west, northwest]
```