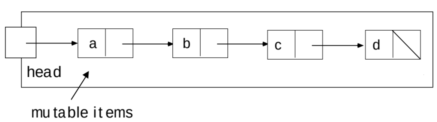
Closed Lists
and
Related Data Structures

Purpose of Closed Lists

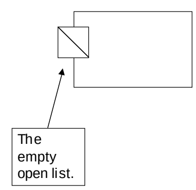
- A closed list is used for its identity as an **object**, rather than purely for its **value** as a sequence.
- Several “clients” can access the same closed list; modifications made by one will be seen by all.
- In some cases, this is the desired behavior.
- In some cases, more space-efficient due to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

Closed List Implementation

- A closed list can be implemented as an “open list in a box”.
- Cells in the list are typically **not shared** from the outside, so they can be mutated.
- Outside access is through a mutable reference called the “**head**”.



An Empty Closed List



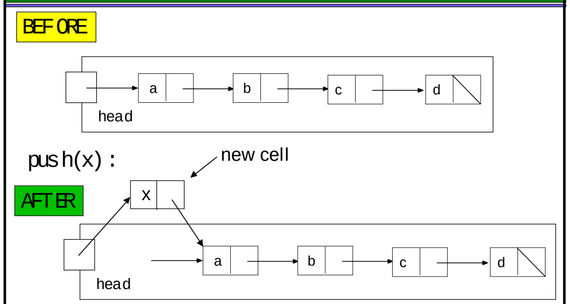
Possible Closed List Usage

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

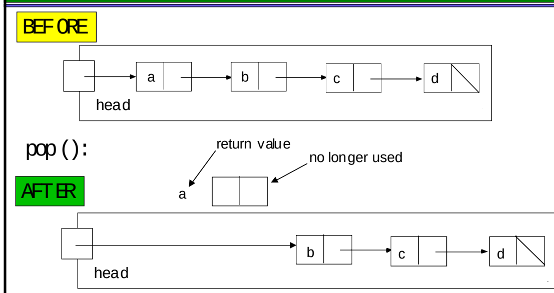
Stack Abstraction

```
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)



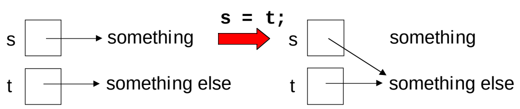
Stack Implementation (pop)



Reading Code

containing References and Pointers

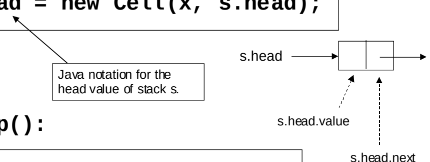
- Suppose s and t are references.
- **Read** the assignment statement
  s = t;
  as "make s point to where t points".
- To see why, consider



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;
```

Push -> Shove

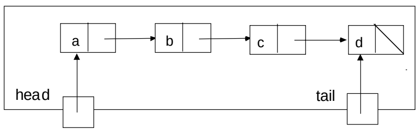
- Define **shove** to be an operation that adds the contents of an entire *open* list to a stack, with the first item in the list being the last item to be added.
- How would this be coded?

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"`

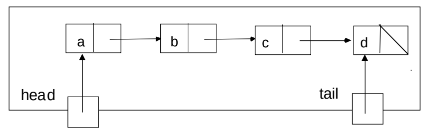
Queue Implementation

- 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?*



Homework

- Write the code for enqueue and dequeue.

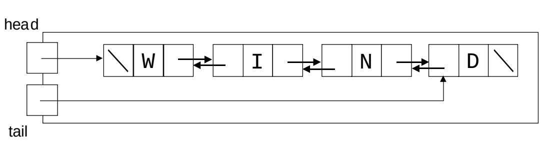
Related Topics

- **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 queues** ("deques", not to be confused with "dequeue").



Deque ("deck") Abstraction

- `void` **`pushFront`**`(Object)`
- `Object` **`popFront`**`()`
- `void` **`pushBack`**`(Object)`
- `Object` **`popBack`**`()`
- `boolean` **`isEmpty`**`()`

return value types

General Doubly-Linked Lists

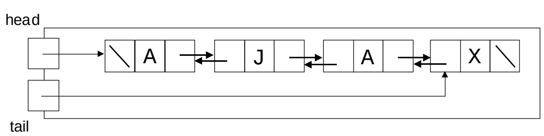
- Extend usage in Deque by allowing insertion and removal at **arbitrary** points
- Can access the object **before** any object, as well as after, unlike singly-linked lists.
- Disadvantages:
  - More storage is used for the extra pointer per cell.
  - Sharing is extremely tricky; better not done.
-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

Doubly-Linked Lists as an Implementation Concept

- In the **implementation** (as opposed to an appropriate 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**, which is convenient for implementation, **does not make an attractive *abstraction***.
- A preferable view is to think in terms of a list **Iterator** (or **Cursor**), which maintains a 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.*;                 // contains LinkedList class

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]
```

Java **Interface** Abstractions

Interface Abstractions in Java

- A principal abstraction mechanism in Java is the formal concept of **interface.**
- An interface is like a **class**, except that it only *declares* methods, it does not implement them.
- A given class may **implement** the interface by giving concrete methods for each of the ones declared in the interface.
- The class definition must assert that it **implements** the interface. The compiler checks that this is the case.

Interface vs. Implementation

```
interface Iterator
{
boolean hasNext();
Object next();
void remove();
}
```

```
import java.util.Iterator;
import polya.*;

class OpenListIterator implements Iterator
{
private OpenList theList;

public OpenListIterator(OpenList theList)// constructor
    {
    this.theList = theList;
    }

public boolean hasNext()
    {
    return !theList.isEmpty();
    }

public Object next()
    {
    Object result = theList.first();
    theList = theList.rest();
    return result;
    }

public void remove()
    {
    throw new UnsupportedOperationException();
    }
```

Not good style actually;
we are forced into it
if using standard Iterator.

Use of an Iterator

```
public static void main(String arg[])
    {
    OpenList L = OpenList.list("a", "b", "c");

    OpenListIterator It = new OpenListIterator(L);

    while( It.hasNext() )
        {
        System.out.println(It.next());
        }
    }
}
```

Important Aspects of Interface

- An interface is a **type**, just as a class is.
- When a variable's type is that of an interface, a variable of **any** implementing class type may be used.
- Any number of distinct classes can implement a given interface.

Implication of second point

The same code can be used for any type of Iterator.

```
void IteratorPrinter(Iterator It)
    {
    while( It.hasNext() )
        {
        System.out.println(It.next());
        }
    }

IteratorPrinter(new OpenListIterator(…));
IteratorPrinter(new ArrayIterator(…));
                   .
                   .
                   .
```

Reemphasis: Power of Interface

- The interface abstraction is powerful, because it does not require the **user** to know **which** implementation is being used.
- The user of a method that specifies an interface argument can thus pass an object of **any class** that implements the interface.

Value of Interfaces

- Interfaces force the provider of a service to give a **clear specification** of what the service is, independent of implementing the service.

Interface Examples with some Implementations (see Java API)

- List
  - Interface: **`List`**
  - Implementations: **`LinkedList, Vector, ArrayList`**
- Set
  - Interface: **`Set`**
  - Implementations: **`HashSet, TreeSet`**
- Comparable interface
  - **`Character, Double, Long, String, BigInteger, Date, etc.`**

More Interface Examples with some Implementations

- ListIterator interface
  - **`listIterator()`** returned by a LinkedList
- Enumeration interface: read-only version of **Iterator**
  - **`elements()`** returned by a Vector, HashTable, or **OpenList**
  - StringTokenizer
- Cloneable interface
  - Many classes