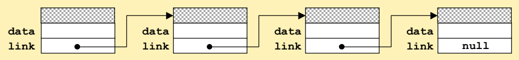
Linking Objects Together

- References are particularly important in computer science because they make it possible to represent the relationship among objects by linking them together in various ways.
- In a **linked list**, each object in a sequence contains a reference to the one that follows it:



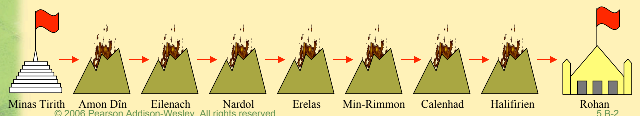
- Java marks the end of linked list using the constant **`null`**, which signifies a reference that does not actually point to an actual object.

The Beacons of Gondor

For answer Gandalf cried aloud to his horse. "On, Shadowfax! We must hasten. Time is short. See! The beacons of Gondor are alight, calling for aid. War is kindled. See, there is the fire on Amon Dîn, and flame on Eilenach; and there they go speeding west: Nardol, Erelas, Min-Rimmon, Calenhad, and the Halifirien on the borders of Rohan."

—J. R. R. Tolkien, *The Return of the King,* 1955

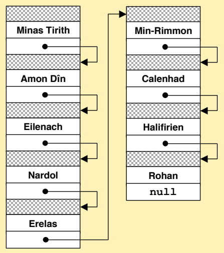
In a scene that was brilliantly captured in Peter Jackson's film adaptation of *The Return of the King,* Rohan is alerted to the danger to Gondor by a succession of signal fires moving from mountain top to mountain top. This scene is a perfect illustration of the idea of message passing in a linked list.



Message Passing in Linked Structures

To represent this message-passing image, you might use a definition such as the one shown on the right.

You can then initialize a chain of **`SignalTower`** objects, like this:



```
public class SignalTower {

/* Constructs a new signal tower */
   public SignalTower(String name,
                      SignalTower link) {
      towerName = name;
      nextTower = link;
   }

/*
 * Signals this tower and passes the
 * message along to the next one.
 */
   public void signal() {
      lightCurrentTower();
      if (nextTower != null) {
         nextTower.signal();
      }
   }

/* Marks this tower as lit */
   public void lightCurrentTower() {
      . . . code to draw a fire on this tower . . .
   }

/* Private instance variables */
   private String towerName;
   private SignalTower nextTower;
}
```

A Reference-Based Implementation of the ADT List

- A reference-based implementation of the ADT list
  - Does not shift items during insertions and deletions
  - Does not impose a fixed maximum length on the list

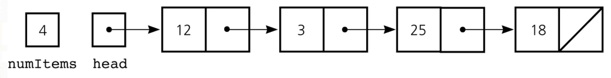


Figure 5-18

A reference-based implementation of the ADT list

A Reference-Based Implementation of the ADT List

- Default constructor
  - Initializes the data fields `numItems` and `head`
- List operations
  - Public methods
    - isEmpty
    - size
    - add
    - remove
    - get
    - removeAll
  - Private method
    - find

Comparing Array-Based and Referenced-Based Implementations

- Size
  - Array-based
    - Fixed size
      - Issues
        - » Can you predict the maximum number of items in the ADT?
        - » Will an array waste storage?
      - Resizable array
        - » Increasing the size of a resizable array can waste storage and time

Comparing Array-Based and Referenced-Based Implementations

- Size (Continued)
  - Reference-based
    - Do not have a fixed size
      - Do not need to predict the maximum size of the list
      - Will not waste storage
- Storage requirements
  - Array-based
    - Requires less memory than a reference-based implementation
      - There is no need to store explicitly information about where to find the next data item

Comparing Array-Based and Referenced-Based Implementations

- Storage requirements (Continued)
  - Reference-based
    - Requires more storage
      - An item explicitly references the next item in the list
- Access time
  - Array-based
    - Constant access time
  - Reference-based
    - The time to access the ith node depends on i

Comparing Array-Based and Referenced-Based Implementations

- Insertion and deletions
  - Array-based
    - Require you to shift the data
  - Reference-based
    - Do not require you to shift the data
    - Require a list traversal

Passing a Linked List to a Method

- A method with access to a linked list's `head` reference has access to the entire list
- When head is an actual argument to a method, its value is copied into the corresponding formal parameter

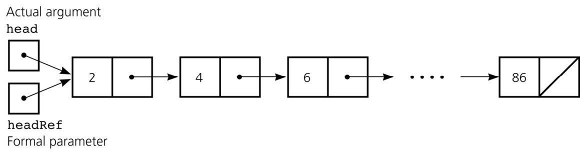


Figure 5-19

A head reference as an argument

Processing Linked Lists Recursively

- Traversal
  - Recursive strategy to display a list

    Write the first node of the list
    Write the list minus its first node
  - Recursive strategies to display a list backward
    - `writeListBackward` strategy

      Write the last node of the list
      Write the list minus its last node backward
    - `writeListBackward2` strategy

      Write the list minus its first node backward
      Write the first node of the list

Processing Linked Lists Recursively

- Insertion
  - Recursive view of a sorted linked list

    The linked list that `head` references is a sorted linked list if
    `head` is `null` (the empty list is a sorted linked list)
    or
    `head.getNext()` is `null` (a list with a single node is a sorted linked list)
    or
    `head.getItem() < head.getNext().getItem()`,
    and `head.getNext()` references a sorted linked list

Variations of the Linked List: Tail References

- `tail` references
  - Remembers where the end of the linked list is
  - To add a node to the end of a linked list

```
tail.setNext(new Node(request, null));
```

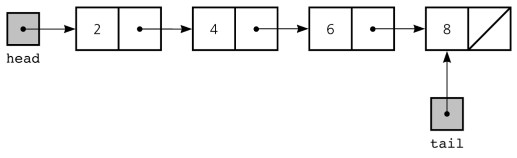


Figure 5-22

A linked list with ***head*** and ***tail*** references

Circular Linked List

- Last node references the first node
- Every node has a successor; check if getNext().equals(list) to determine when entire list is traversed

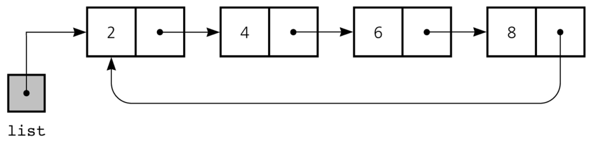


Figure 5-23

A circular linked list

Circular Linked List

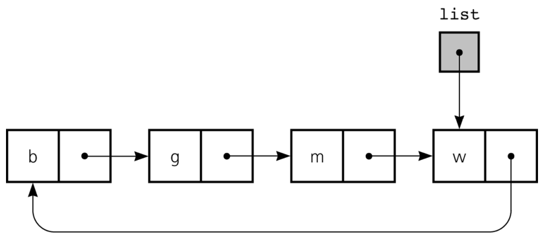


Figure 5-24

A circular linked list with an external reference to the last node

Dummy Head Nodes

- Dummy head node
  - Always present, even when the linked list is empty
  - Insertion and deletion algorithms initialize `prev` to reference the dummy head node, rather than `null`

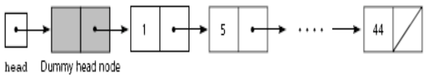


Figure 5-25

A dummy head node

Doubly Linked List

- Each node references both its predecessor and its successor
- Dummy head nodes are useful in doubly linked lists

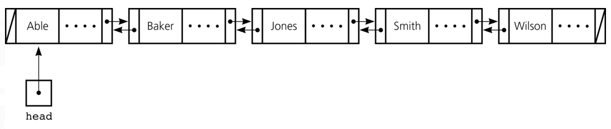


Figure 5-26

A doubly linked list

Doubly Linked List

- Circular doubly linked list
  - `prev` reference of the dummy head node references the last node
  - `next` reference of the last node references the dummy head node
  - Eliminates special cases for insertions and deletions

Doubly Linked List

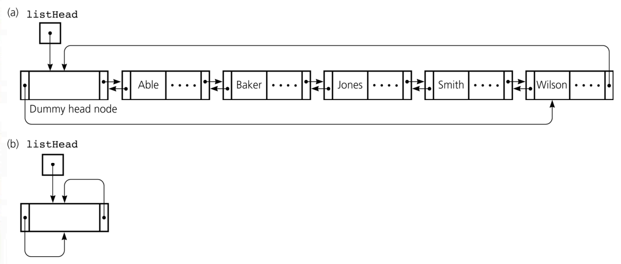


Figure 5-27

a) A circular doubly linked list with a dummy head node; b) an empty list with a dummy head node

Doubly Linked List

- To delete the node that `curr` references

```
curr.getPrev().setNext(curr.getNext());
curr.getNext().setPrev(curr.getPrev());
```

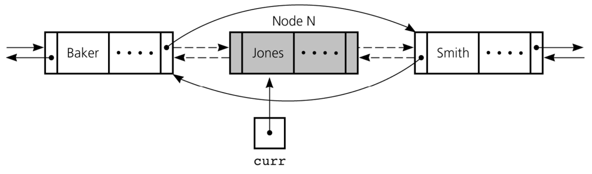


Figure 5-28

Reference changes for deletion

Doubly Linked List

- To insert a new node that `newNode` references before the node referenced by `curr`

```
newNode.setNext(curr);
newNode.setPrev(curr.getPrev());
curr.setPrev(newNode);
newNode.getPrev().setNext(newNode);
```

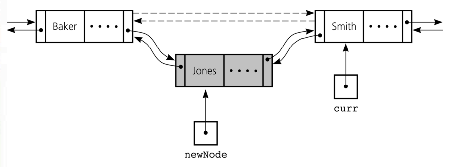


Figure 5-29

Reference changes for insertion

Application: Maintaining an Inventory

- Stages of the problem-solving process
  - Design of a solution
  - Implementation of the solution
  - Final set of refinements to the program
- Operations on the inventory
  - List the inventory in alphabetical order by title (L command)
  - Find the inventory item associated with title (I, M, D, O, and S commands)
  - Replace the inventory item associated with a title (M, D, R, and S commands)
  - Insert new inventory items (A and D commands)

The Java Collections Framework

- Implements many of the more commonly used ADTs
- Collections framework
  - Unified architecture for representing and manipulating collections
  - Includes
    - Interfaces
    - Implementations
    - Algorithms

Generics

- JCF relies heavily on Java *generics*
- Generics
  - Develop classes and interfaces and defer certain data-type information
    - Until you are actually ready to use the class or interface
- Definition of the class or interface is followed by *<E>*
  - *E* represents the data type that client code will specify

Iterators

- Iterator
  - Gives the ability to cycle through items in a collection
  - Access next item in a collection by using iter.next()
- JCF provides two primary iterator interfaces
  - java.util.Iterator
  - java.util.ListIterator
- Every ADT collection in the JCF has a method to return an iterator object

Iterators

- `ListIterator` methods
  - **void** `add(E o)`
  - **boolean** `hasNext()`
  - **boolean** `hasPrevious()`
  - `E next()`
  - **int** `nextIndex()`
  - `E previous()`
  - **int** `previousIndex()`
  - **void** `remove()`
  - **void** `set(E o)`

The Java Collection's Framework `List` Interface

- JCF provides an interface `java.util.List`
- List interface supports an ordered collection
  - Also known as a sequence
- Methods
  - **boolean** `add(E o)`
  - **void** `add(`**int** `index, E element)`
  - **void** `clear()`
  - **boolean** `contains(Object o)`
  - **boolean** `equals(Object o)`
  - `E get(`**int** `index)`
  - **int** `indexOf(Object o)`

The Java Collection's Framework `List` Interface

- Methods (continued)
  - **boolean** `isEmpty()`
  - `Iterator<E> iterator()`
  - `ListIterator<E> listIterator()`
  - `ListIterator<E> listIterator(int index)`
  - `E remove(`**int** `index)`
  - **boolean** `remove(Object o)`

The Java Collection's Framework `List` Interface

- Methods (continued)
  - `E set(`**int** `index, E element)`
  - **int** `size()`
  - `List<E> subList(`**int** `fromIndex,` **int** `toIndex)`
  - `Object[] toArray()`

Summary

- Reference variables can be used to implement the data structure known as a linked list
- Each reference in a linked list is a reference to the next node in the list
- Algorithms for insertions and deletions in a linked list involve
  - Traversing the list from the beginning until you reach the appropriate position
  - Performing reference changes to alter the structure of the list

Summary

- Inserting a new node at the beginning of a linked list and deleting the first node of a linked list are special cases
- An array-based implementation uses an implicit ordering scheme; a reference-based implementation uses an explicit ordering scheme
- Any element in an array can be accessed directly; you must traverse a linked list to access a particular node
- Items can be inserted into and deleted from a reference-based linked list without shifting data

Summary

- The `new` operator can be used to allocate memory dynamically for both an array and a linked list
  - The size of a linked list can be increased one node at a time more efficiently than that of an array
- A binary search of a linked list is impractical
- Recursion can be used to perform operations on a linked list
- The recursive insertion algorithm for a sorted linked list works because each smaller linked list is also sorted

Summary

- A tail reference can be used to facilitate locating the end of a list
- In a circular linked list, the last node references the first node
- Dummy head nodes eliminate the special cases for insertion into and deletion from the beginning of a linked list
- A head record contains global information about a linked list
- A doubly linked list allows you to traverse the list in either direction

Summary

- Generic class or interface
  - Enables you to defer the choice of certain data-type information until its use
- Java Collections Framework
  - Contains interfaces, implementations, and algorithms for many common ADTs
- Collection
  - Object that holds other objects
  - Iterator cycles through its contents