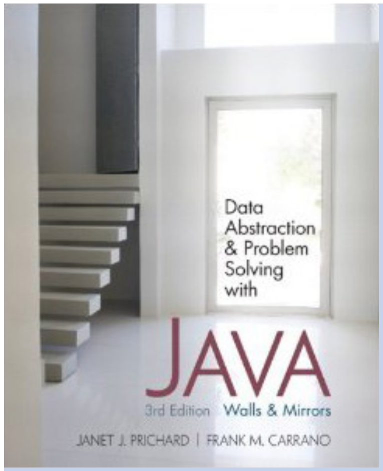

Data Abstraction & Problem Solving with
JAVA
3rd Edition Walls & Mirrors
JANET J. PRICHARD | FRANK M. CARRANO

Chapter 5

Linked Lists

Preliminaries

- Options for implementing an ADT
  - Array
    - Has a fixed size
    - Data must be shifted during insertions and deletions
  - Linked list
    - Is able to grow in size as needed
    - Does not require the shifting of items during insertions and deletions

Preliminaries

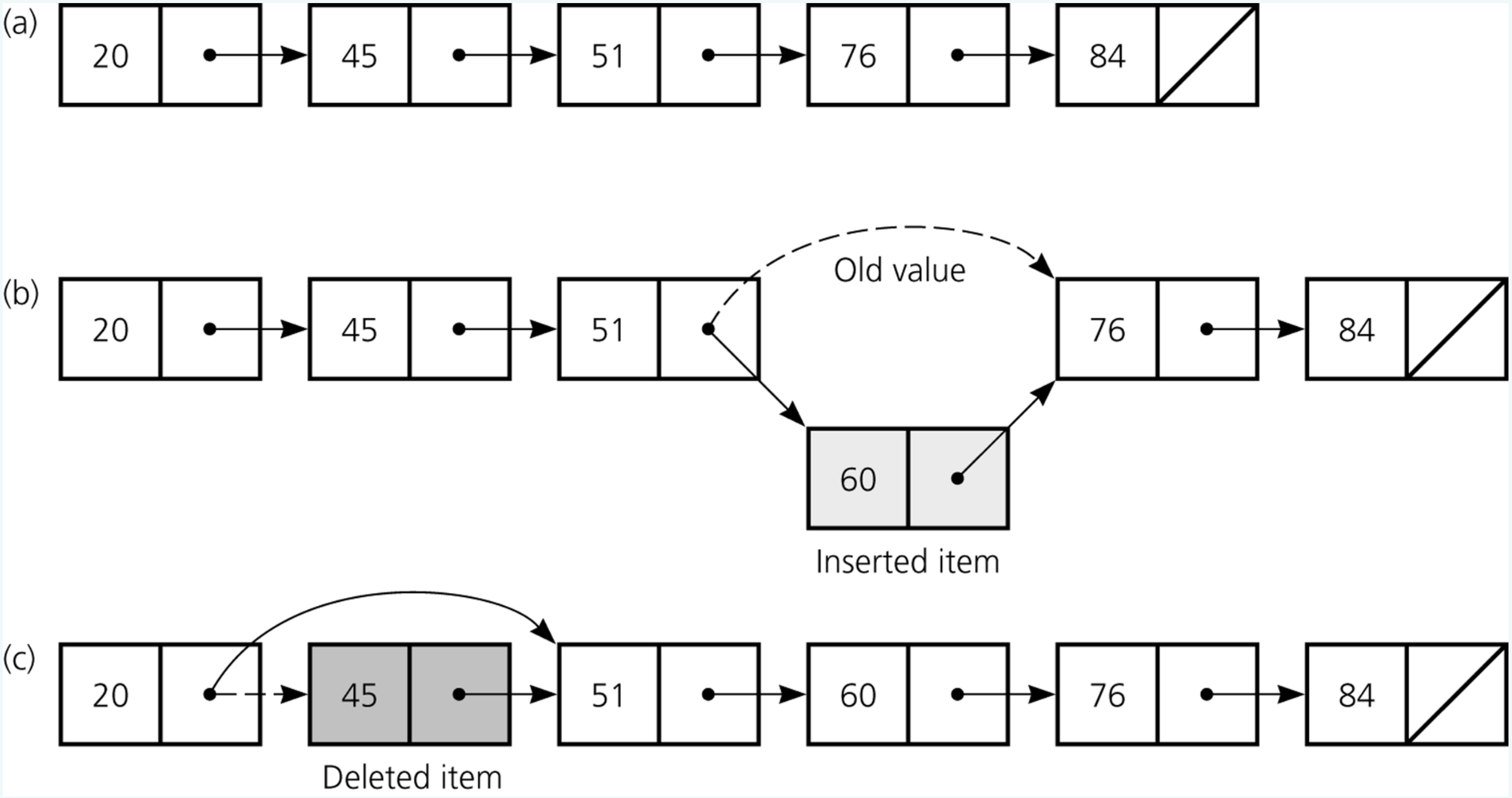


Figure 5-1

a) A linked list of integers; b) insertion; c) deletion

Object References

- A reference variable
  - Contains the location of an object
  - Example

    ```
    Integer intRef;
    intRef = new Integer(5);
    ```

  - As a data field of a class
    - Has the default value `null`
  - A local reference variable to a method
    - Does not have a default value

Object References

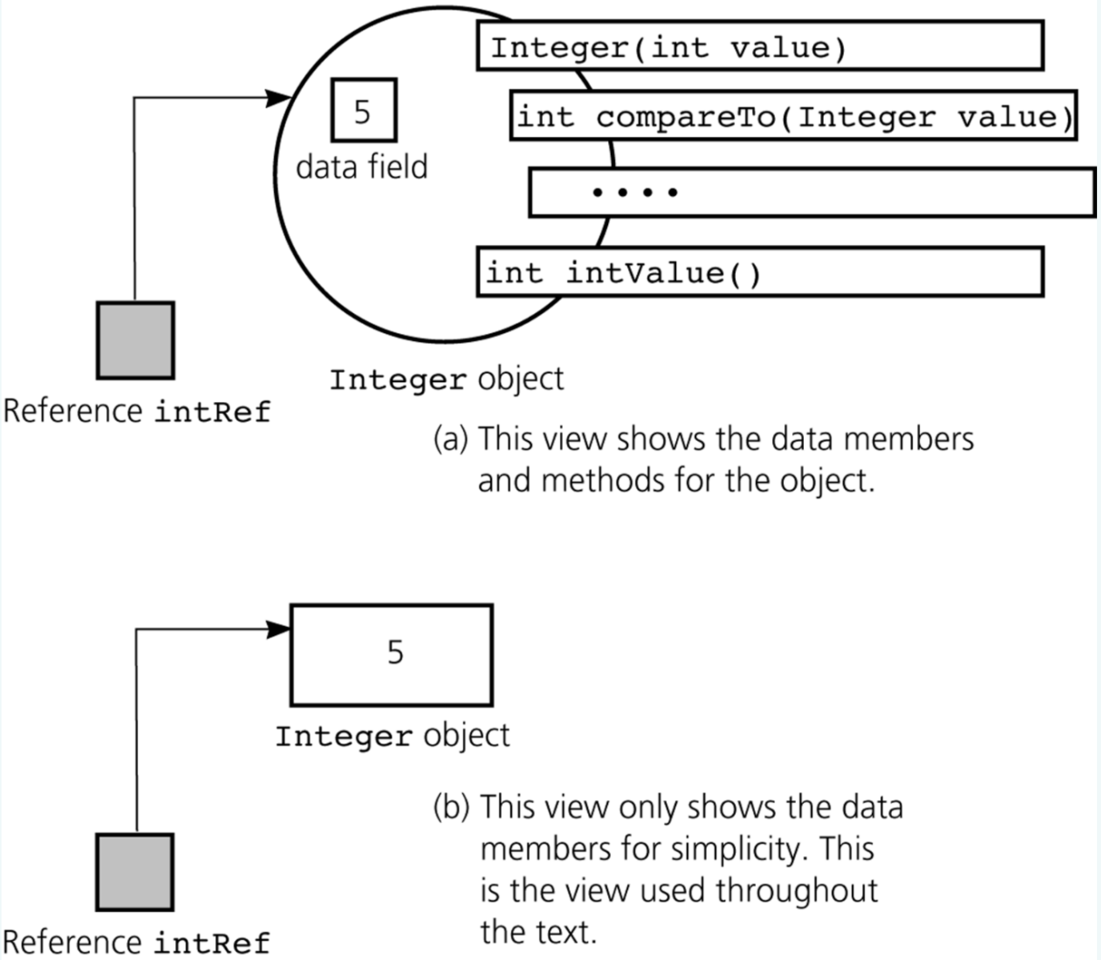

Integer(int value)
int compareTo(Integer value)
....
int intValue()
5
data field
Reference intRef
Integer object
(a) This view shows the data members and methods for the object.
5
Integer object
Reference intRef
(b) This view only shows the data members for simplicity. This is the view used throughout the text.

Figure 5-2

A reference to an ***Integer*** object

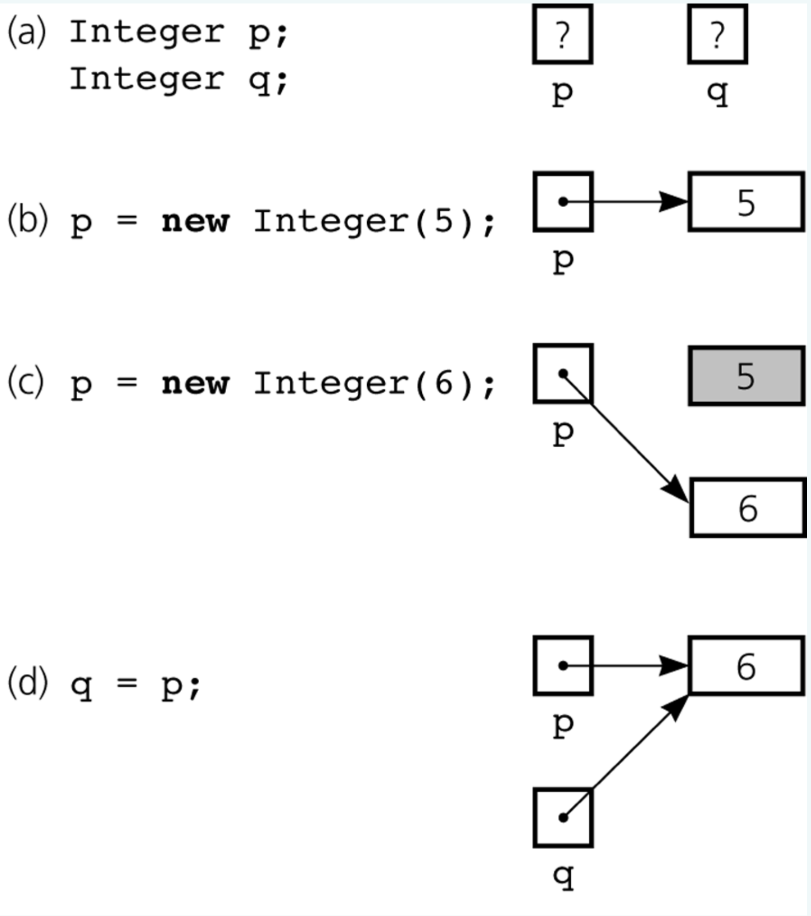
Object References

- When one reference variable is assigned to another reference variable, both references then refer to the same object

```
Integer p, q;
p = new Integer(6);
q = p;
```

- A reference variable that no longer references any object is marked for garbage collection

Object References



(a)
```
Integer p;
Integer q;
```

(b)
```
p = new Integer(5);
```

(c)
```
p = new Integer(6);
```

(d)
```
q = p;
```

Figure 5-3a-d

a) Declaring reference variables; b) allocating an object; c) allocating another object, with the dereferenced object marked for garbage collection

Object References

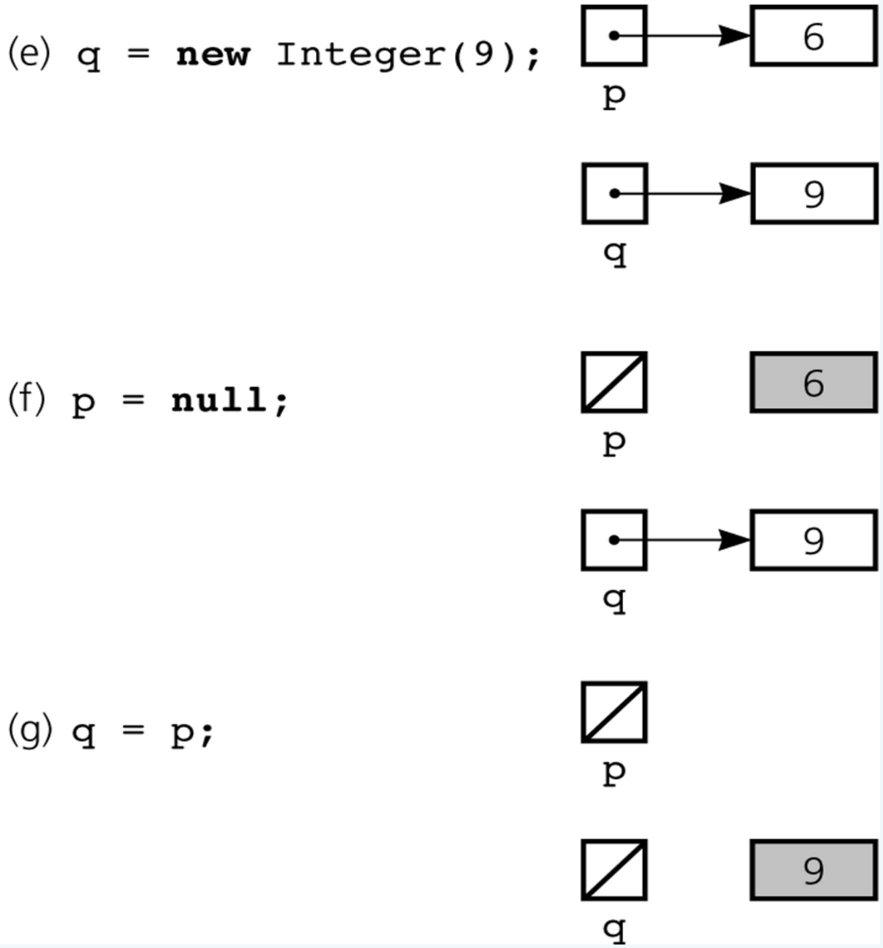


Figure 5-3e-g

e) allocating an object; f) assigning ***null*** to a reference variable; g) assigning a reference with a ***null*** value

Object References

- An array of objects
  - Is actually an array of references to the objects
  - Example

    ```
    Integer[] scores = new Integer[30];
    ```

  - Instantiating Integer objects for each array reference

    ```
    scores[0] = new Integer(7);
    scores[1] = new Integer(9); // and so on …
    ```

Object References

- Equality operators (== and `!=`)
  - Compare the values of the reference variables, not the objects that they reference
- `equals` method
  - Compares objects field by field
- When an object is passed to a method as an argument, the reference to the object is copied to the method' s formal parameter
- Reference-based ADT implementations and data structures use Java references

Resizable Arrays

- The number of references in a Java array is of fixed size
- Resizable array
  - An array that grows and shrinks as the program executes
  - An illusion that is created by using an allocate and copy strategy with fixed-size arrays
- `java.util.Vector` class
  - Uses a similar technique to implement a growable array of objects

Reference-Based Linked Lists

- Linked list
  - Contains nodes that are linked to one another
  - A node contains both data and a link to the next item
  - Access is package-private

```
package List;
class Node {
    Object item;
    Node next;
    // constructors, accessors,
    // and mutators …
} // end class Node
```

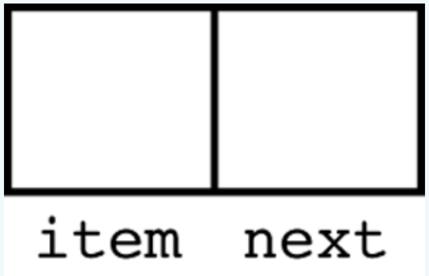


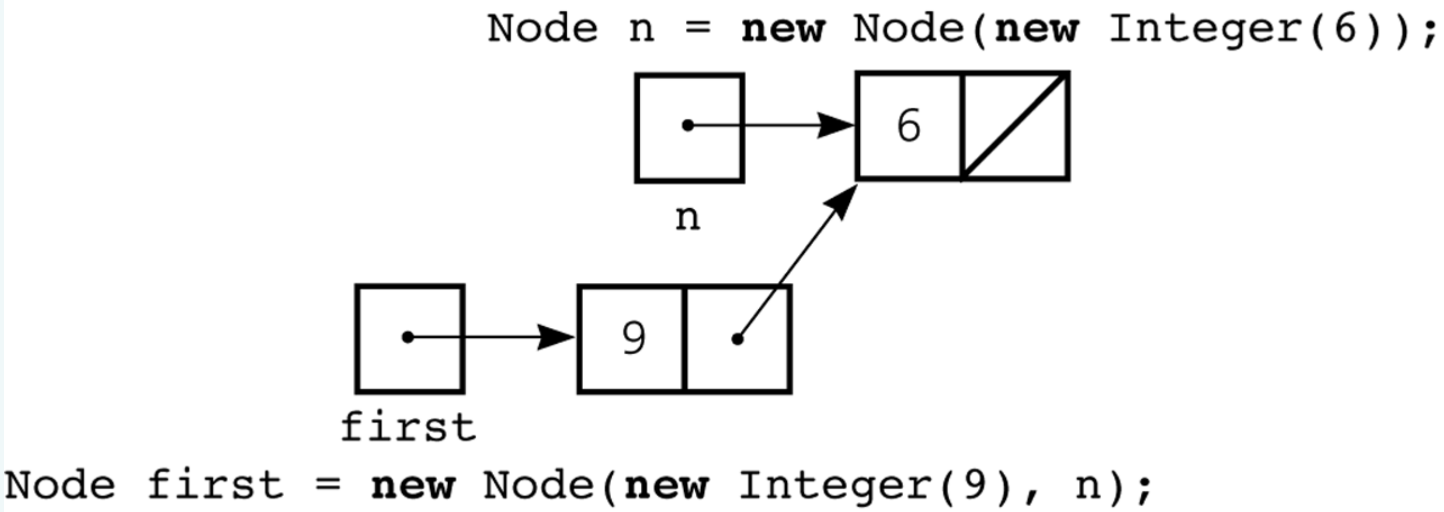
Figure 5-5

A node

Reference-Based Linked Lists

- Using the Node class

```
Node n = new Node (new Integer(6));
Node first = new Node (new Integer(9), n);
```



```
Node n = new Node(new Integer(6));
```

```
Node first = new Node(new Integer(9), n);
```

Figure 5-7

Using the ***Node*** constructor to initialize a data field and a link value

Reference-Based Linked Lists

- Data field `next` in the last node is set to `null`
- `head` reference variable
  - References the list' s first node
  - Always exists even when the list is empty

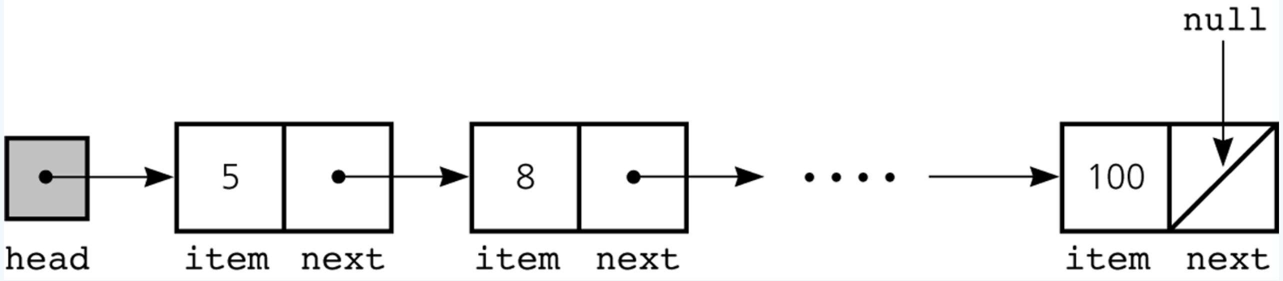


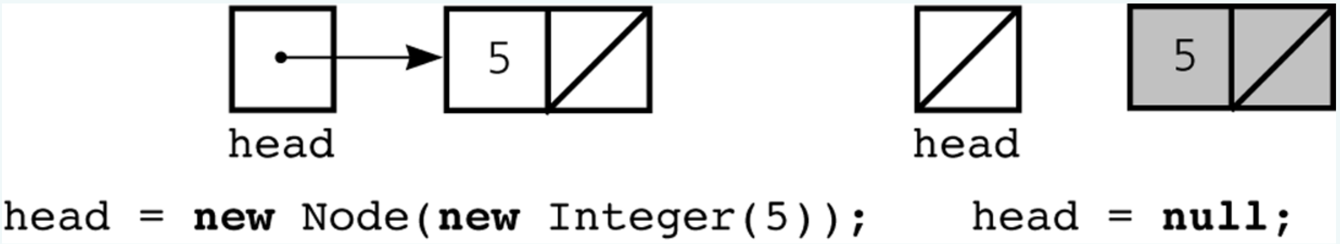
Figure 5-8

A ***head*** reference to a linked list

Reference-Based Linked Lists

- `head` reference variable can be assigned `null` without first using `new`
  - Following sequence results in a lost node

```
head = new Node(); // Don’t really need to use new here
head = null; // since we lose the new Node object here
```



```
head = new Node(new Integer(5));
```

```
head = null;
```

Figure 5-9

A lost node

Programming with Linked Lists: Displaying the Contents of a Linked List

- `curr` reference variable
  - References the current node
  - Initially references the first node
- To display the data portion of the current node

```
System.out.println(curr.item);
```

- To advance the current position to the next node

```
curr = curr.next;
```

Displaying the Contents of a Linked List

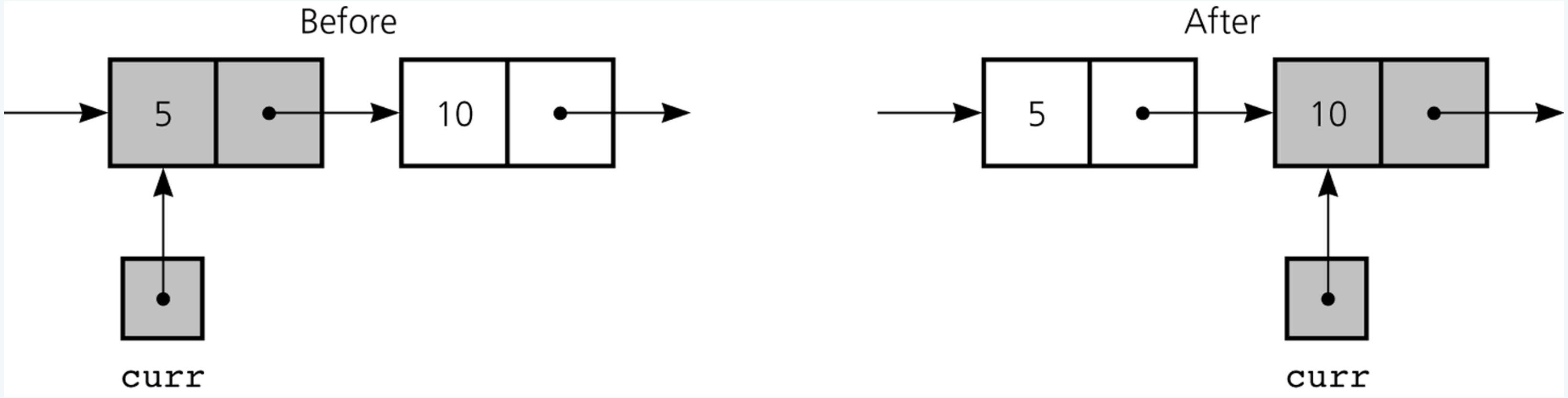


Figure 5-10

The effect of the assignment ***curr = curr.next***

Displaying the Contents of a Linked List

- To display all the data items in a linked list

```
for (Node curr = head; curr != null; curr =
     curr.next) {
 System.out.println(curr.item);
} // end for
```

Deleting a Specified Node from a Linked List

- To delete node N which `curr` references
  - Set `next` in the node that precedes N to reference the node that follows N

```
prev.next = curr.next;
```

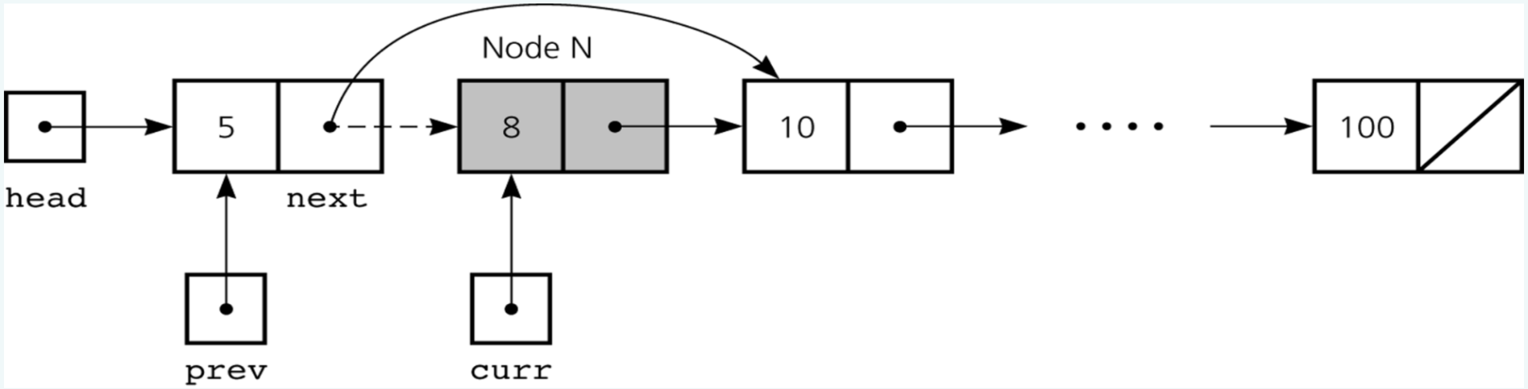


Figure 5-11

Deleting a node from a linked list

Deleting a Specified Node from a Linked List

- Deleting the first node is a special case

```
head = head.next;
```

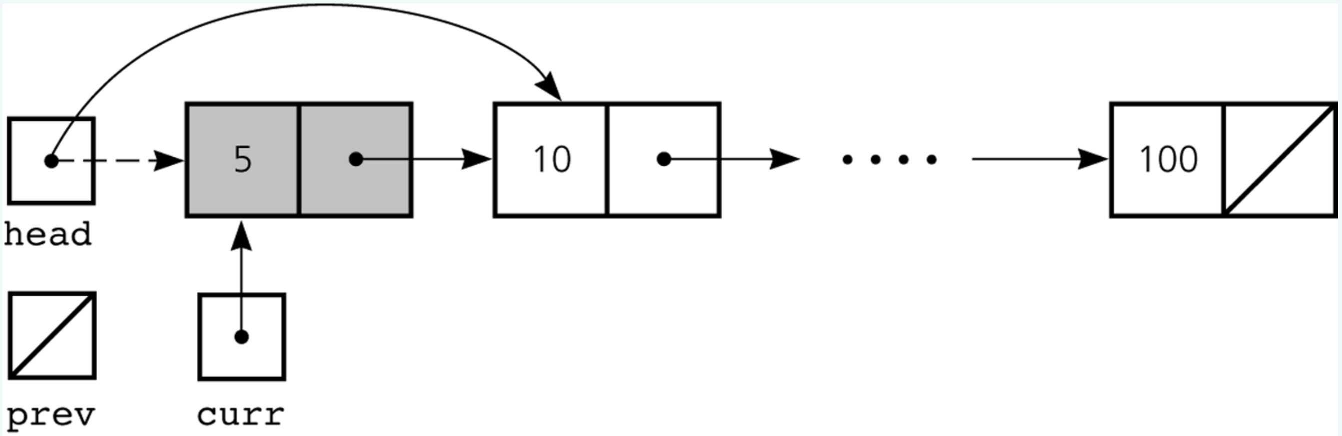


Figure 5-12

Deleting the first node

Deleting a Specified Node from a Linked List

- To return a node that is no longer needed to the system

```
curr.next = null;
curr = null;
```

- Three steps to delete a node from a linked list
  - Locate the node that you want to delete
  - Disconnect this node from the linked list by changing references
  - Return the node to the system

Inserting a Node into a Specified Position of a Linked List

- To create a node for the new item

```
newNode = new Node(item);
```

- To insert a node between two nodes

```
newNode.next = curr;
prev.next = newNode;
```

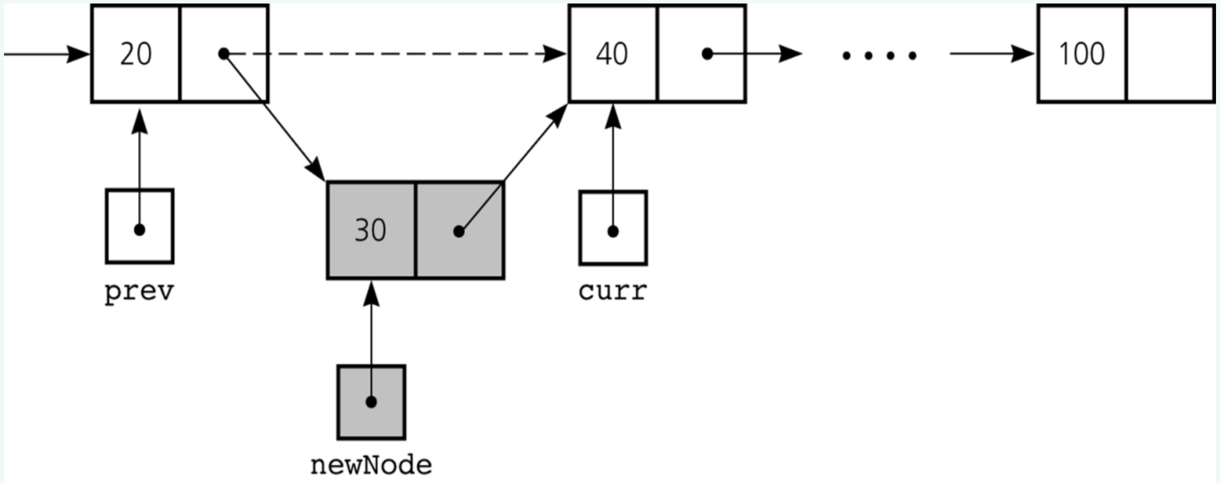


Figure 5-13

Inserting a new node into a linked list

Inserting a Node into a Specified Position of a Linked List

- To insert a node at the beginning of a linked list

```
newNode.next = head;
head = newNode;
```

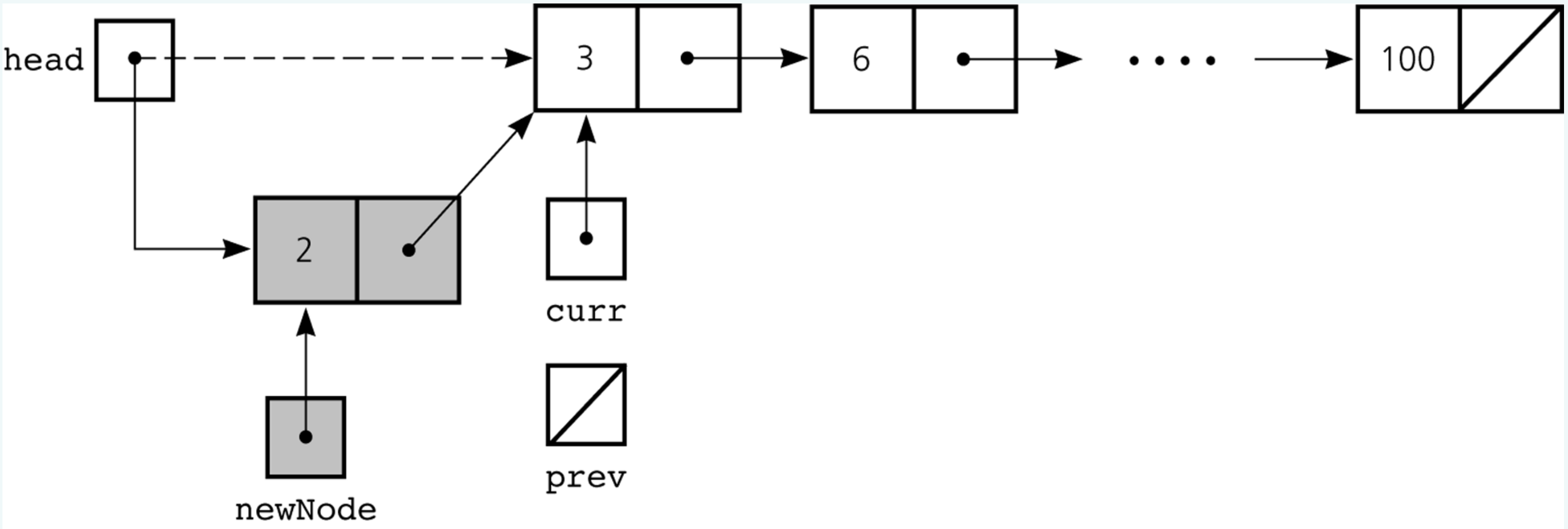


Figure 5-14

Inserting at the beginning of a linked list

Inserting a Node into a Specified Position of a Linked List

- Inserting at the end of a linked list is not a special case if `curr` is `null`

```
newNode.next = curr;
prev.next = newNode;
```

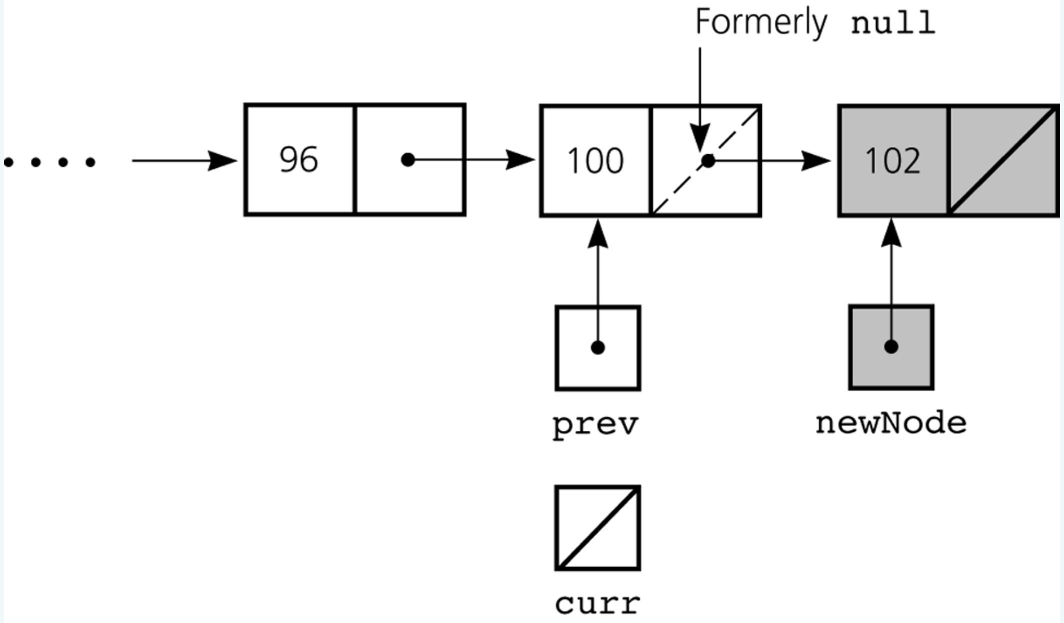


Figure 5-15

Inserting at the end of a linked list

Inserting a Node into a Specified Position of a Linked List

- Three steps to insert a new node into a linked list
  - Determine the point of insertion
  - Create a new node and store the new data in it
  - Connect the new node to the linked list by changing references

Determining `curr` and `prev`

- Determining the point of insertion or deletion for a sorted linked list of objects

```
for ( prev = null, curr = head;
        (curr != null) &&
        (newValue.compareTo(curr.item) > 0);
        prev = curr, curr = curr.next ) {
} // end for
```

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

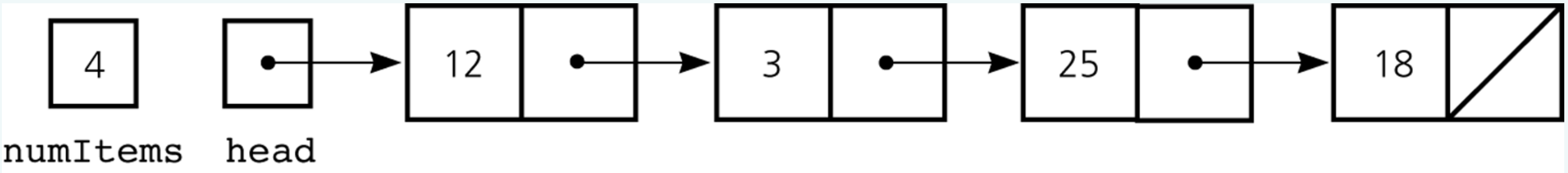


Figure 5-18

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 i^{th} 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

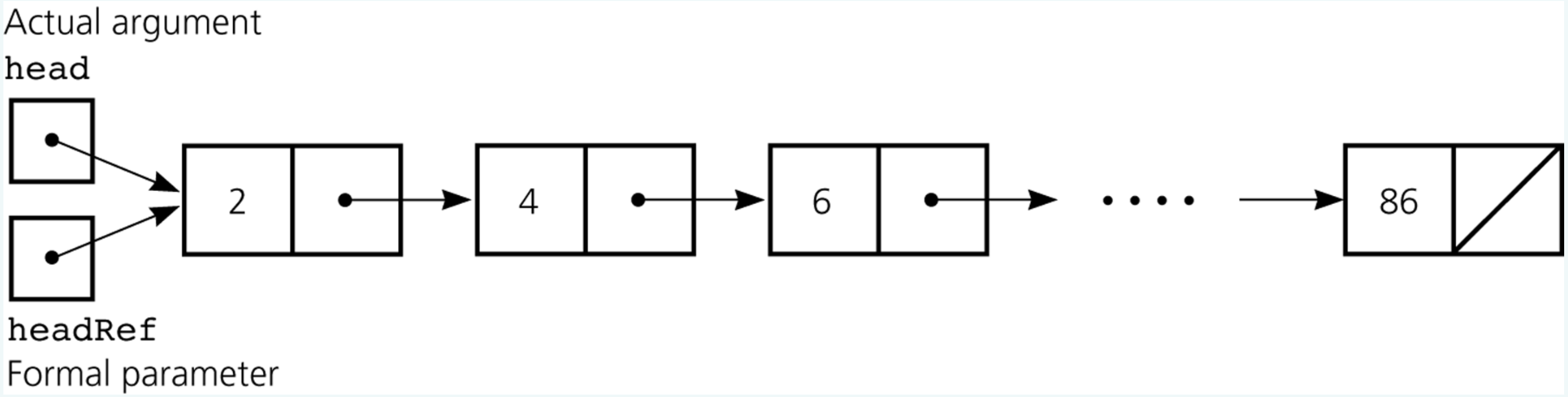


Figure 5-19

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.next` is `null` (a list with a single node is a sorted linked list)

    or

    `head.item < head.next.item`,

    and `head.next` 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.next = new Node(request, null);
```

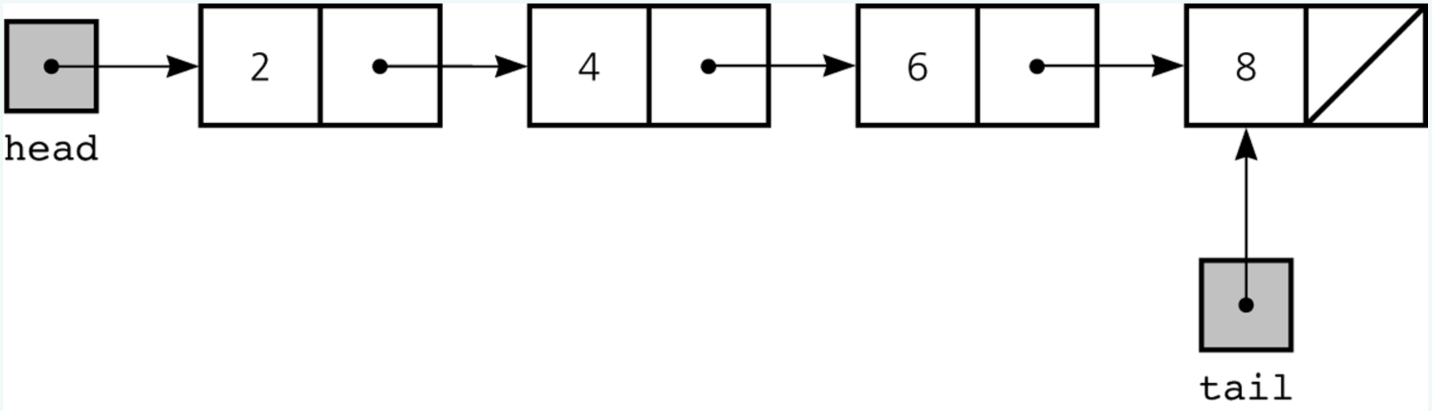


Figure 5-22

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

Circular Linked List

- Last node references the first node
- Every node has a successor

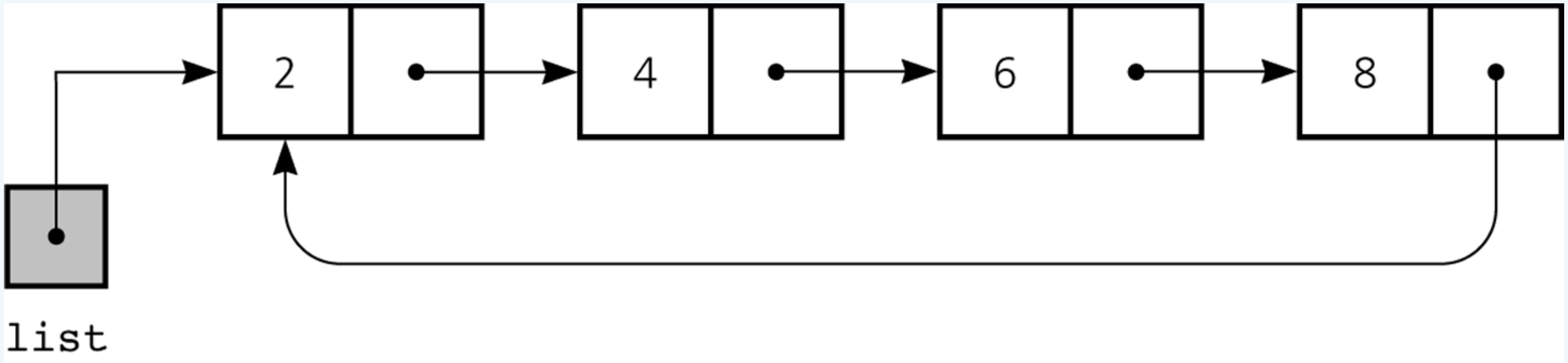


Figure 5-23

A circular linked list

Circular Linked List

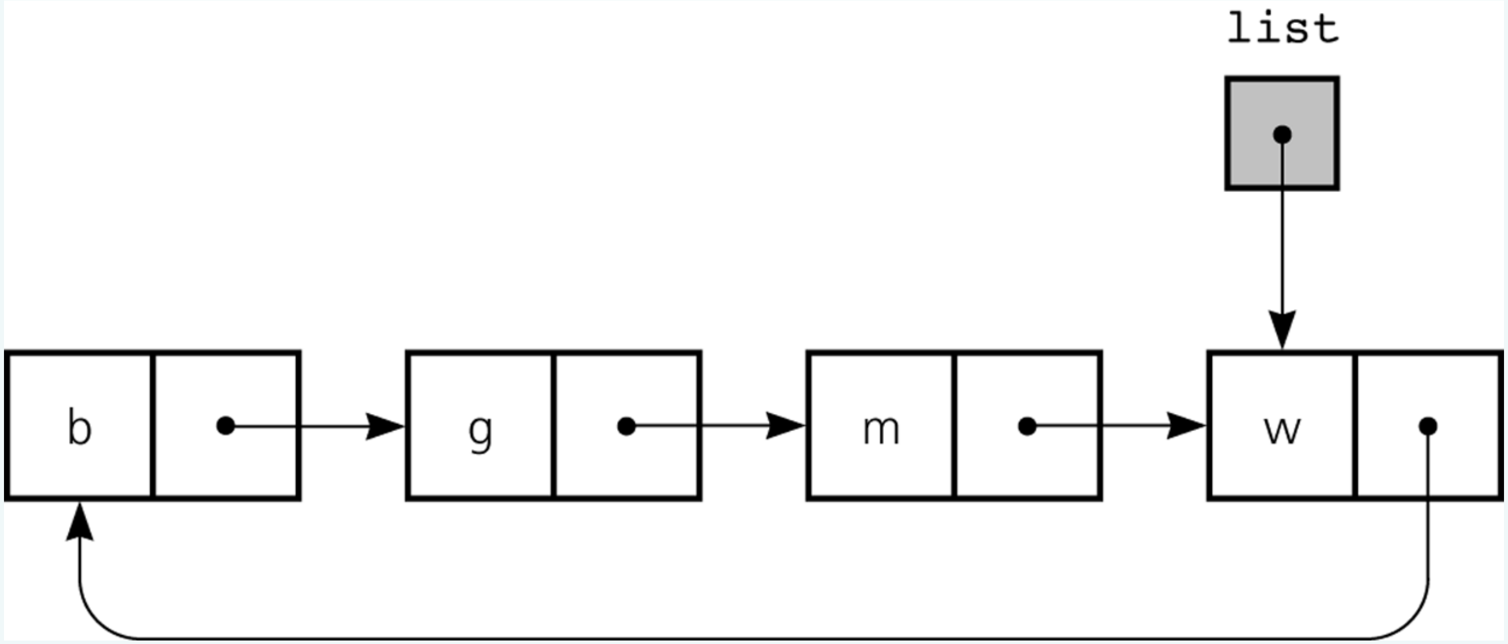


Figure 5-24

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`

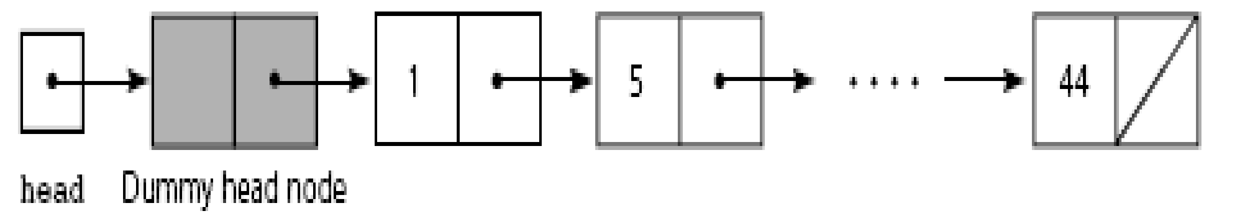


Figure 5-25

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

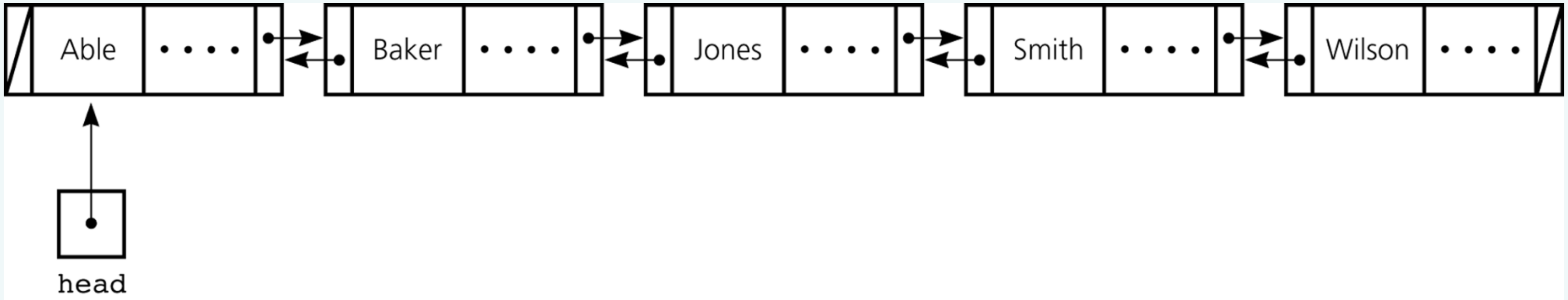


Figure 5-26

A doubly linked list

Doubly Linked List

- Circular doubly linked list
  - `preceding` 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

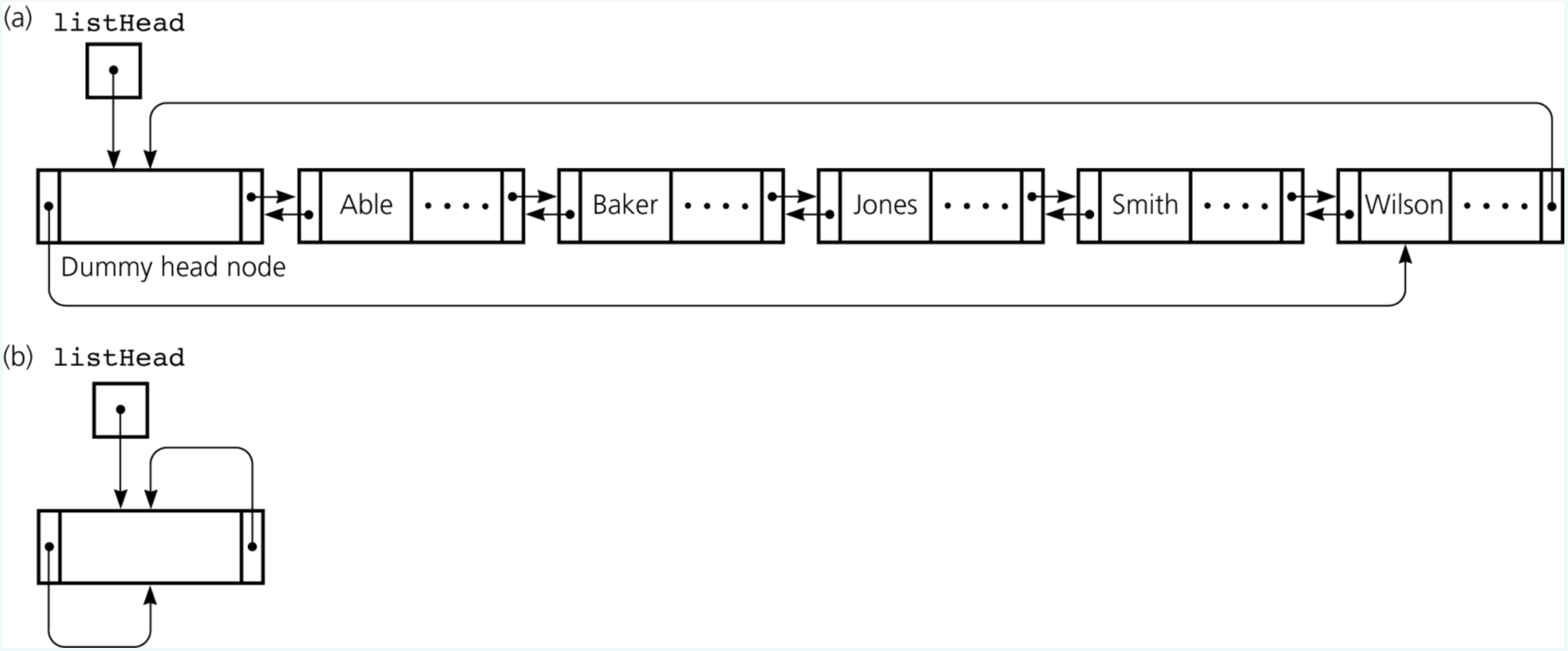


Figure 5-27

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.preceding.next = curr.next;
curr.next.preceding = curr.preceding;
```

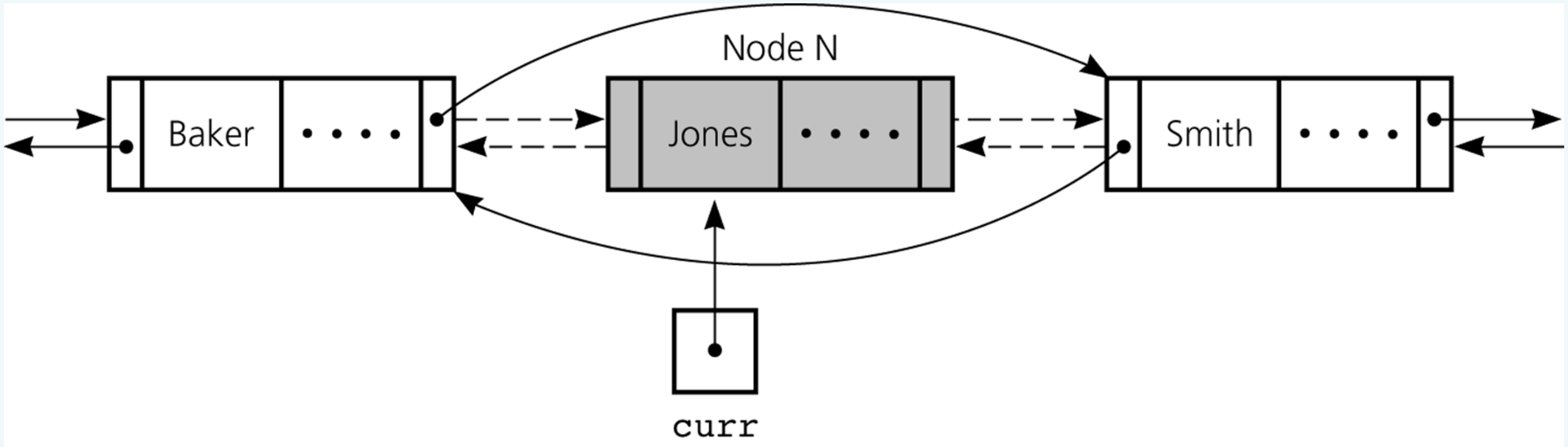


Figure 5-28

Reference changes for deletion

Doubly Linked List

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

```
newNode.next = curr;
newNode.preceding = curr.preceding;
curr.preceding = newNode;
newNode.preceding.next = newNode;
```

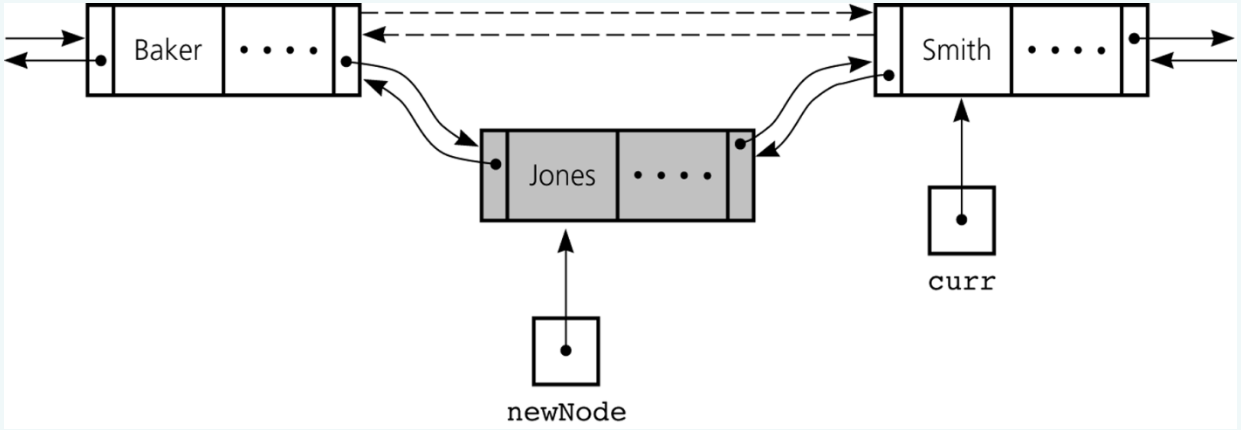


Figure 5-29

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 have 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