CS 171: Introduction to Computer Science II

Linked List

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What we have learned so far

- Basic data structure
  - –Arrays
- Abstract data types
  - –Stacks
    - Last-In-First-Out (LIFO)
    - Operations: push, pop
  - –Queues
    - First-In-First-Out (FIFO)
    - Operations: enqueue, dequeue

Arrays

- **Arrays** have certain disadvantages:
  - Search is slow in unordered array
  - Insertion is slow in ordered array
  - Deletion is slow in both cases
  - Both insertion into ordered array and deletion require moving elements
  - Difficult to support dynamic size

A Different Data Structure

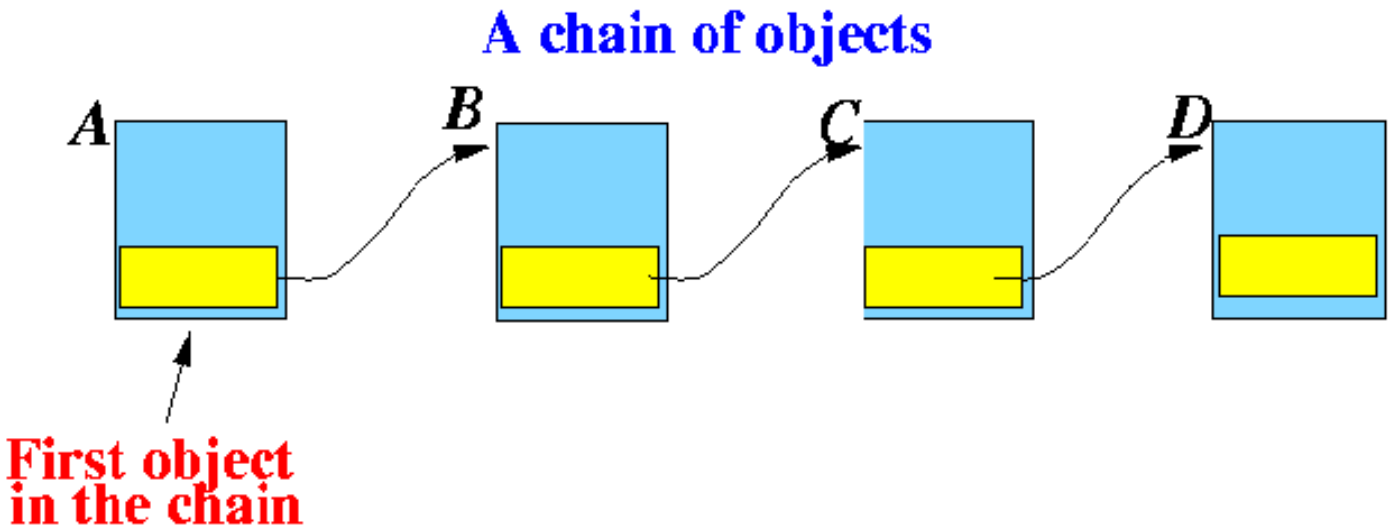
- **Linked List**
  - A general-purpose storage structure
  - Can replace arrays in many cases
  - Insertion and deletion are fast
  - Truly supports dynamic size

Linked list

- Linked list concept
- Linked list operations
- Different versions of linked list
- Re-implementing stacks and queues using linked list

Linked List

- A Linked List is a sequence of nodes chained together.
- Each **node**, element, or link contains a **data item**, and a **reference** to next node



Node

```
class Node {
    Item item;
    Node next;
}
```

Data

Reference to the next node

- This is called ***self-referential***.
  - A class containing a reference to itself.

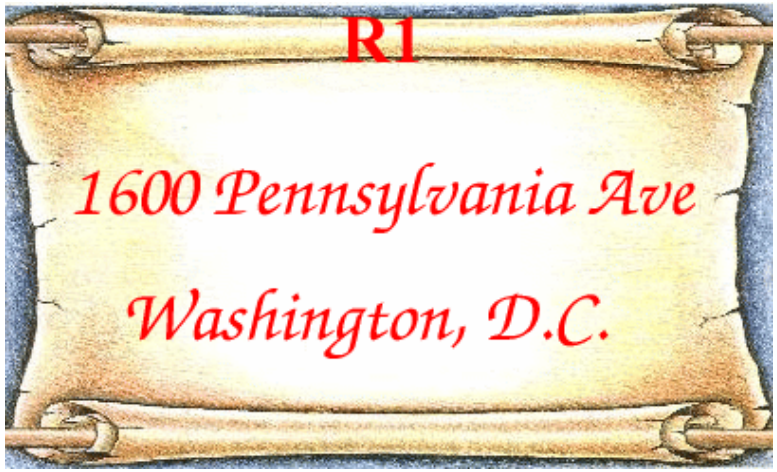
Self-Referential

- In Java, an object type variable stores a reference, a **pointer**, to an object,

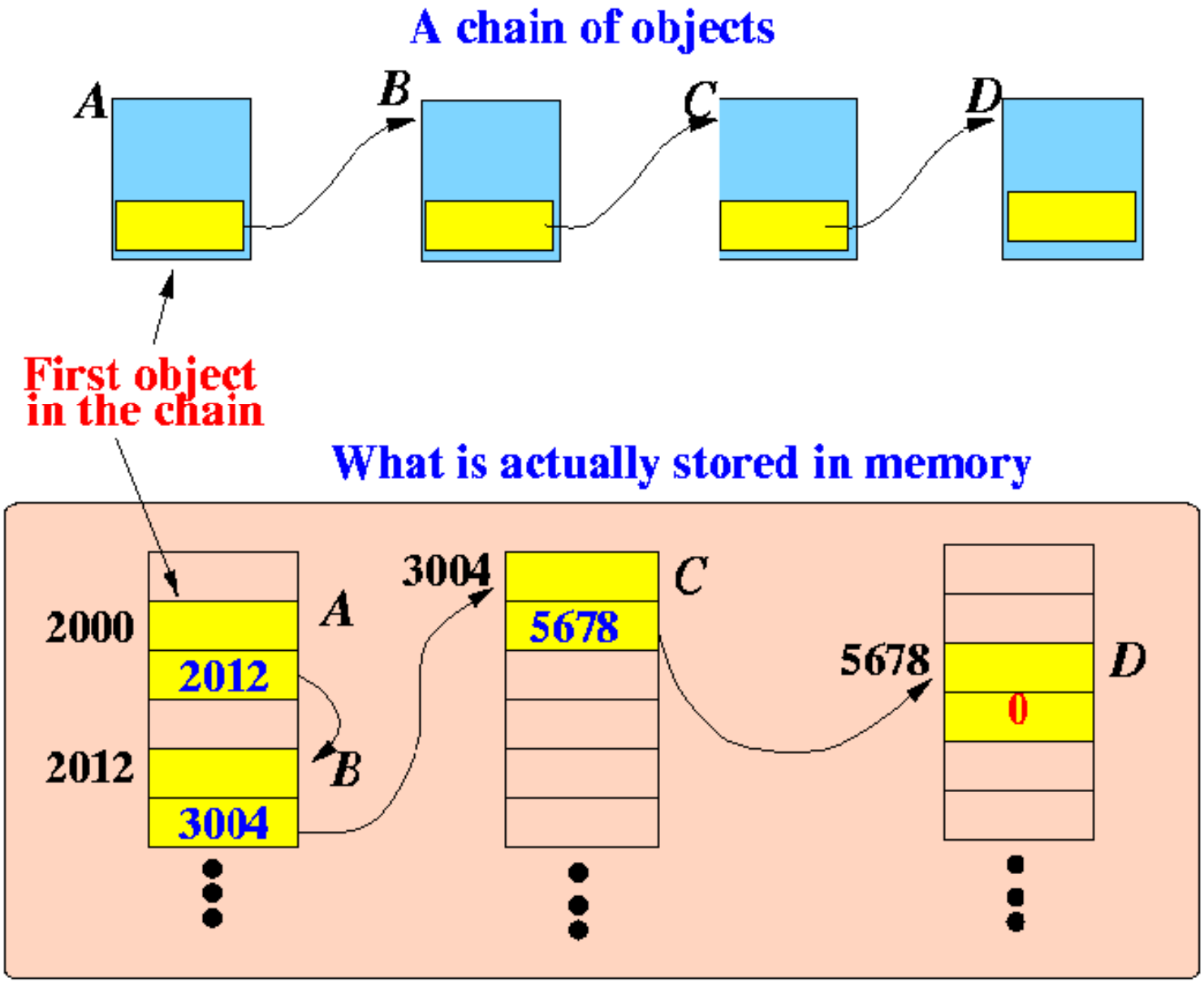
  it does not contain the object.
- A reference is a memory address to the actual object.
- All references are of the same size: (regardless of what they point to)
  - 4 bytes in a 32-bit program
  - 8 bytes in a 64-bit program

Object vs. Object Reference

object **object *reference***



Linked List


A chain of objects
A
B
C
D
First object
in the chain
What is actually stored in memory
2000
2012
2012
3004
A
B
3004
5678
C
5678
0
D

Difference with Arrays

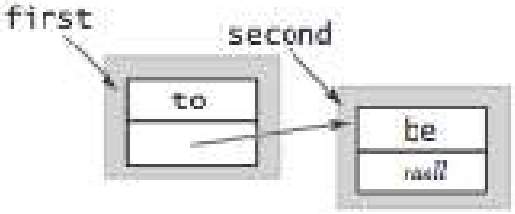
- The major difference of Linked List with Array is that Array stores elements continuously in memory while linked list does not.
- Linked list supports dynamic size
- There is no simple indexing in Linked List.
- Linked List incurs some memory overhead, because of the need to store references.

Building a linked list

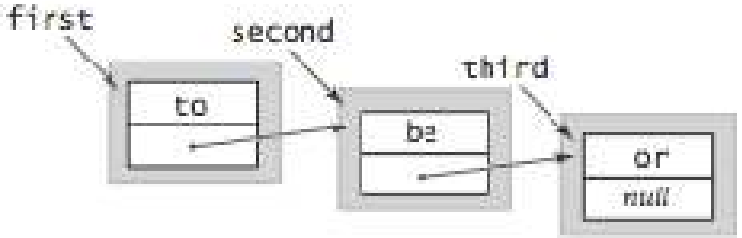
- Example: to build a linked list that contains the items ”to”, ”be”, and ”or”
- Create a Node for each item
  - –set the item field to the desired value
  - –set the next field to next node
- Maintains a link to the first node of the list, also called root, head

```
Node first  = new Node();
first.item  = "to";
```


```
Node second = new Node();
second.item = "be";
first.next  = second;
```




```
Node third  = new Node();
third.item  = "or";
second.next = third;
```

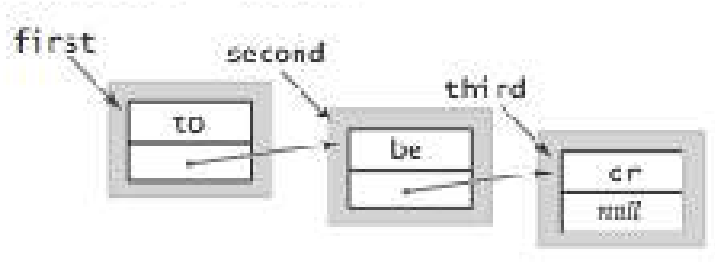


Linked List Operations

- **Insert**
  - Inserts an element at the front.
  - It's possible to insert at the end as well.
- **Find** (**search**)
  - Find an element with a specific key.
- **Delete**
  - Delete an element at the front
  - Delete an element with a specific key

Insert at the beginning

- Example: insert “not” at the beginning

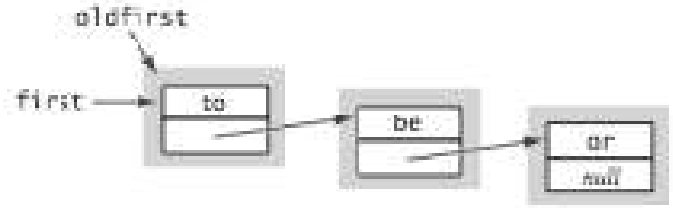


Insert at the beginning

- Example: insert “not” at the beginning

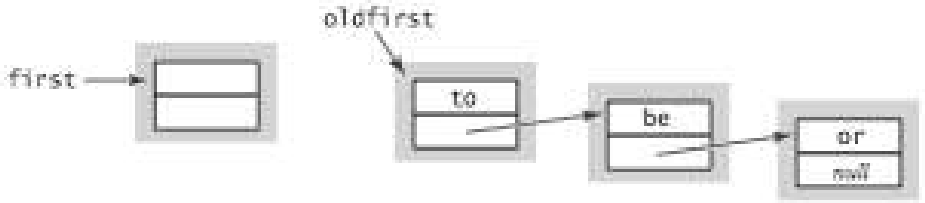
save a link to the list

```
Node oldfirst = first;
```



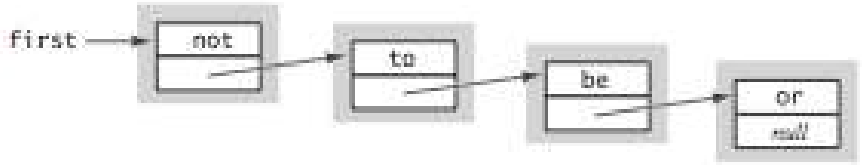
create a new node for the beginning

```
first = new Node();
```



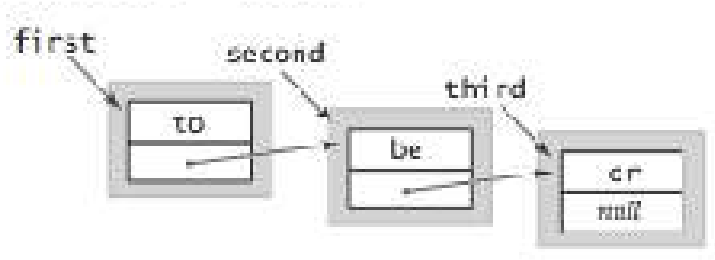
set the instance variables in the new node

```
first.item = "not";
first.next = oldfirst;
```



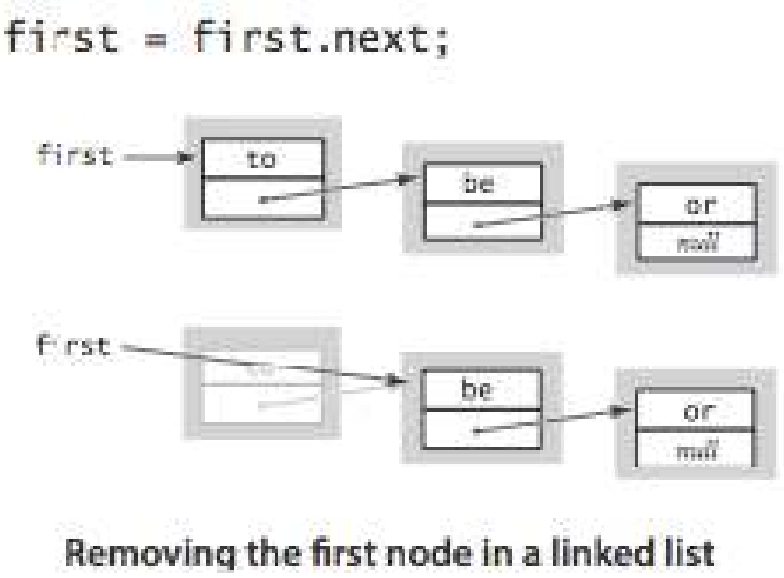
Remove from the beginning

- Example: remove “to” at the beginning



Remove from the beginning

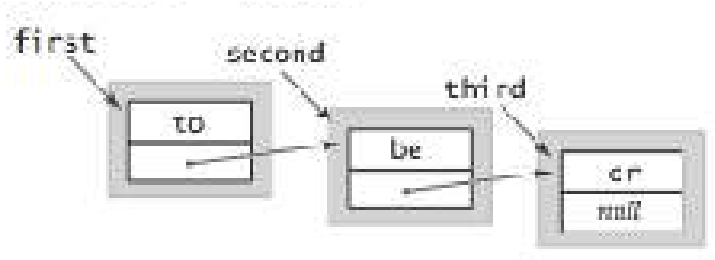
- Example: remove “to” at the beginning
- Set the root to the next node in the list



Removing the first node in a linked list

Insert at the end

- Example: insert “not” at the end

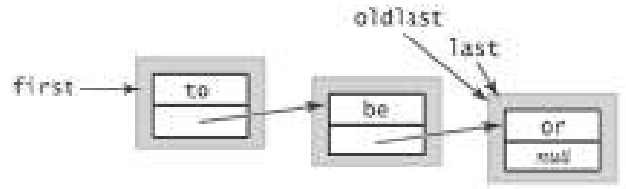


Insert at the end

- Example: insert “not” at the end
- Maintain a link to the last node in the list

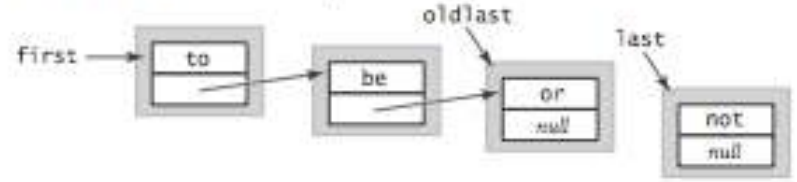
save a link to the last node

```
Node oldlast = last;
```



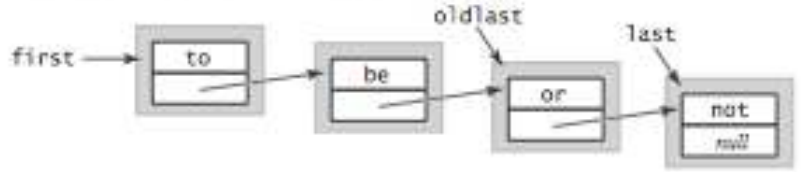
create a new node for the end

```
Node last = new Node();
last.item = "not";
```



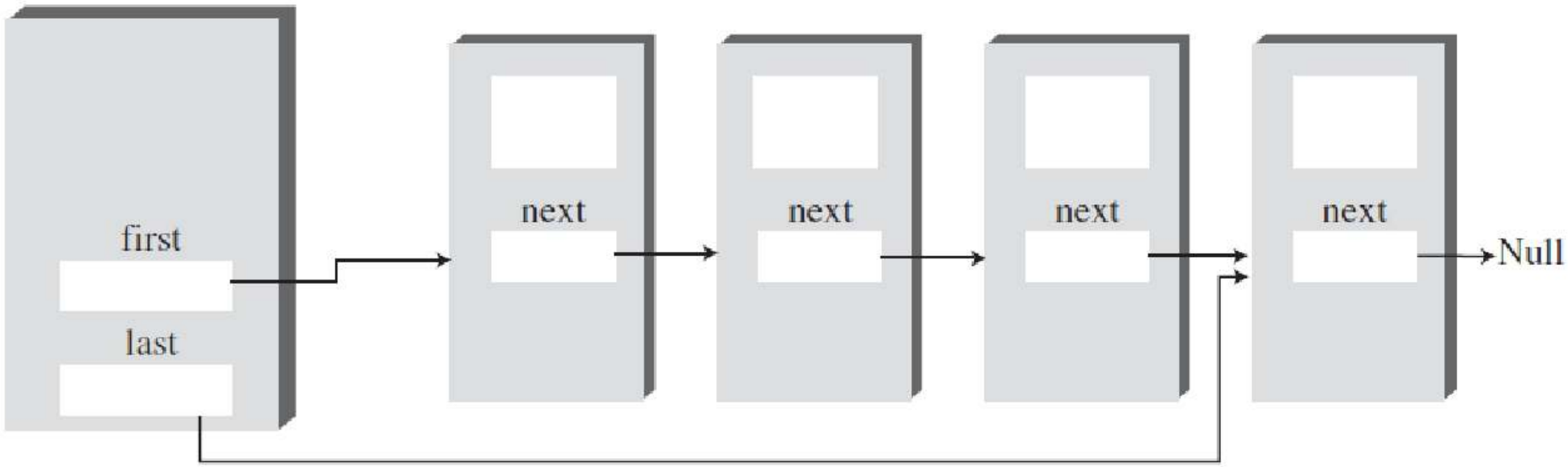
link the new node to the end of the list

```
oldlast.next = last;
```



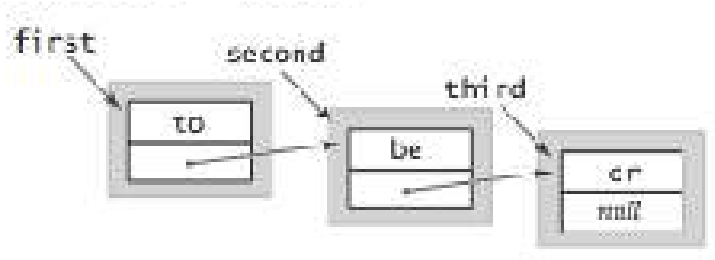
Double-ended Linked List

- Similar to an ordinary linked list, but in addition to keep ‘first’, it also keeps a reference to the ‘last’ element in the list.
- What happens when the list is empty? Has only one element?



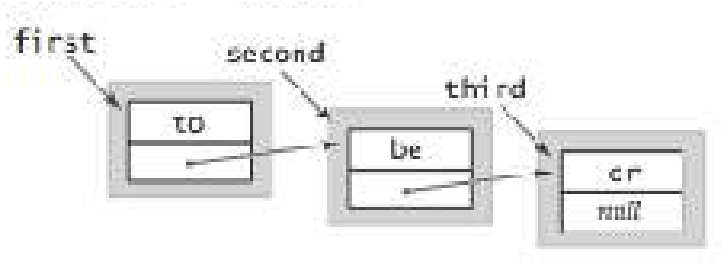
Traversing a linked list

- Example: print out the values of the linked list



Traversing a linked list

- Example: print out the values of the linked list



- Traversing a linked list

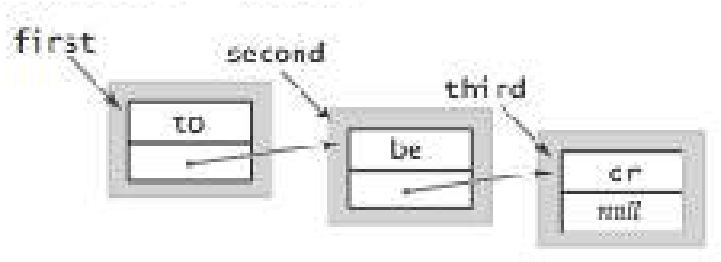
```
for (Node x = first; x != null; x = x.next) {
    // process x.item
}
```

- Traversing an array

```
for (int i = 0; i< N; i++) {
    // process a[i]
}
```

Search in a linked list

- Example: search if there is “be” in the linked list

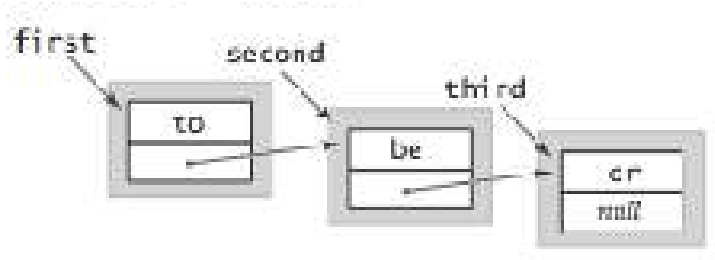


- Traversing a linked list

```
for (Node x = first; x != null; x = x.next) {
    if x.item.equals(“be”) return x;
}
```

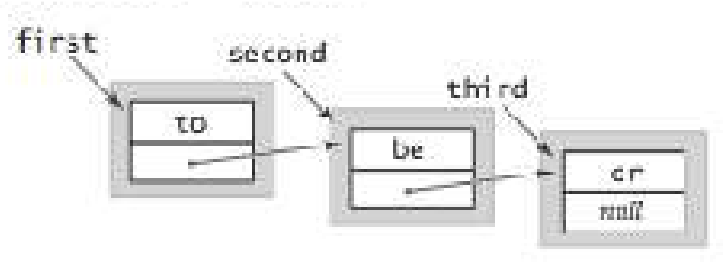
Remove a given item

- Example: remove “be” from the linked list



Remove a given item

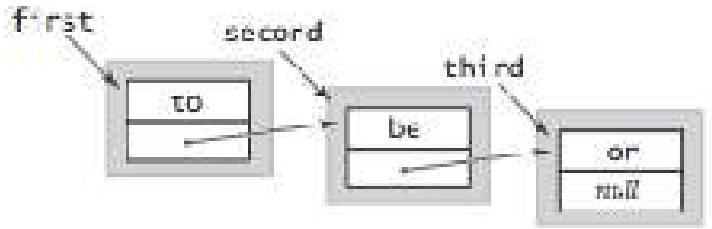
- Example: remove “be” from the linked list
- Search the item in the list, then remove it




```
for (Node x = first; x != null; x = x.next) {
    if x.item.equals(“be”)
    // remove x?
}
```

Remove a given item

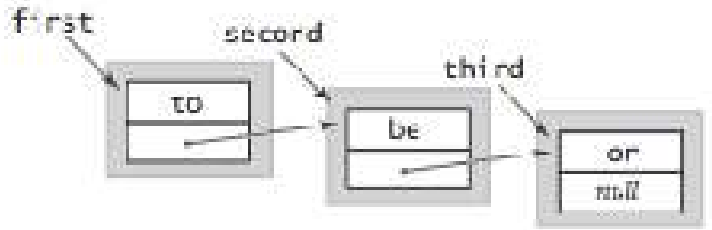
- Example: remove “be” from the linked list
- Search the item, then remove it
- Need to keep the reference to the ***previous*** element as well as current element.




```
Node current = first;
Node previous = first;
while (current != null && !current.item.equals(“be”)){
     previous = current;
     current = current.next;
}
// remove current?
previous.next = current.next;
```

Remove a given item

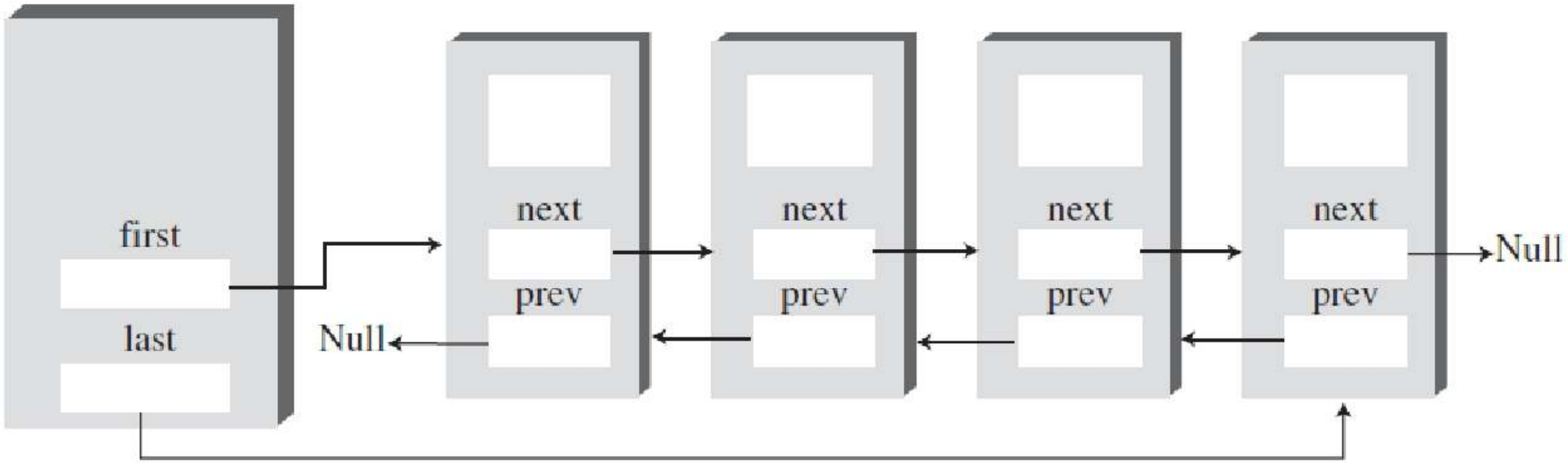
- Example: remove “be” from the linked list
- Search the item, then remove it
- Need to keep the reference to the ***previous*** element as well as current element.
- Need to consider the case when current is first




```
Node current = first;
Node previous = first;
while (current != null && !current.item.equals(“be”)){
     previous = current;
     current = current.next;
}
// remove current
if (current == first)
     first = first.next;
else
     previous.next = current.next;
```

Doubly Linked List

- A doubly linked list has **bidirectional** references, one pointing to the **next** link, and one pointing to the **previous** link.



Doubly Linked List

- **Pros**: flexibility
- **Cons**: complexity, memory consumption
- For clarity, we often call the ordinary linked list explicitly as **singly linked list.**
- Do not confuse Doubly Linked List with Double-ended List!

Linked List vs. Arrays

- Both are general purpose data structures
- Linked list support faster delete
- Linked list truly support dynamic size (compares favorably even with expandable arrays)
- Linked list does occur memory overhead
- Linked list does not support index based access

- (Singly) linked list
- Double ended linked list
- Doubly linked list

Halloween Costume – Linked List

Doubly Linked List

Circularly Linked List

Binary Tree

Null Pointer

Linked list

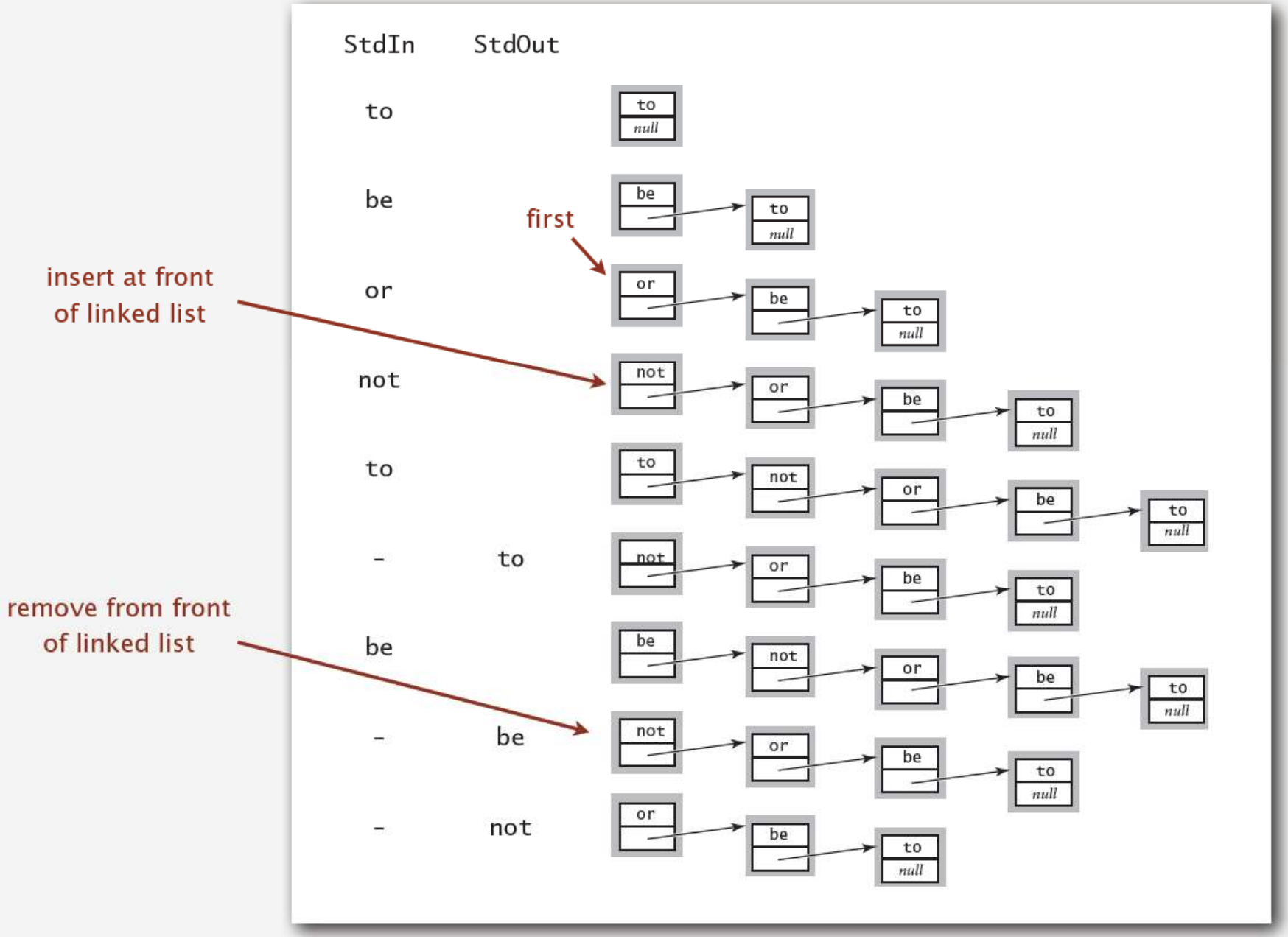
- Linked list concept
- Linked list operations
- Different versions of linked list
- Re-implementing stacks and queues using linked list

Using Linked List

- Linked List is **interchangeable** with array
  in many cases, we can re-implement Stacks and Queues using Linked List.
- Implementing Stack using Linked List
  - The underlying storage using a linked list instead of an array
  - The stack interface methods are exactly the same with before.

Stack: linked-list representation

Maintain pointer to first node in a linked list; insert/remove from front.



Stack pop: linked-list implementation

inner class

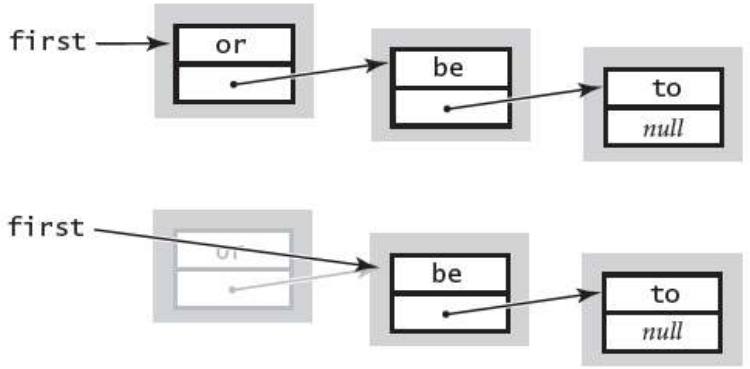
```
public class Node
{
   String item;
   Node next;
...
}
```

save item to return

```
String item = first.item;
```

delete first node

```
first = first.next;
```



return saved item

```
return item;
```

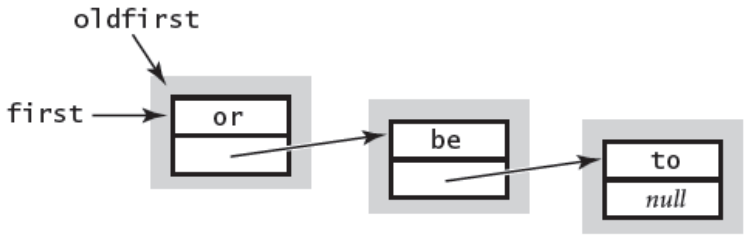
Stack push: linked-list implementation

inner class

```
public class Node
{
   String item;
   Node next;
...
}
```

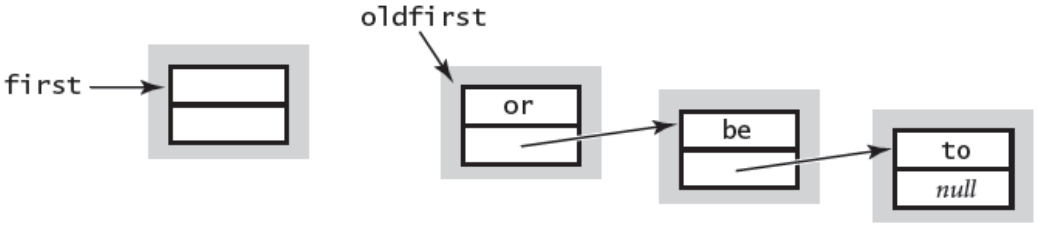
save a link to the list

```
Node oldfirst = first;
```



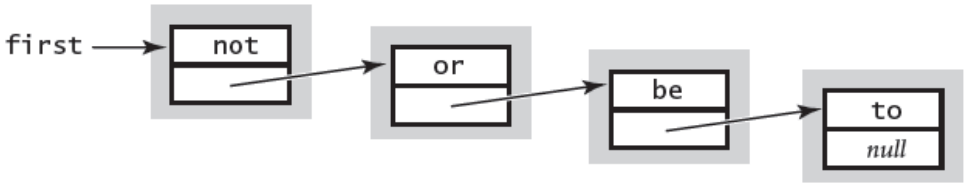
create a new node for the beginning

```
first = new Node();
```



set the instance variables in the new node

```
first.item = "not";
first.next = oldfirst;
```



Stack: linked-list implementation in Java

```
public class LinkedStackOfStrings
{
   private Node first = null;

   private class Node
   {
      String item;
      Node next;
   }

   public boolean isEmpty()
   {  return first == null;  }

   public void push(String item)
   {
      Node oldfirst = first;
      first = new Node();
      first.item = item;
      first.next = oldfirst;
   }

   public String pop()
   {
      String item = first.item;
      first = first.next;
      return item;
   }
}
```

Generic stack: linked-list implementation

```
public class LinkedStackOfStrings
{
   private Node first = null;

   private class Node
   {
      String item;
      Node next;
   }

   public boolean isEmpty()
   {  return first == null;  }

   public void push(String item)
   {
      Node oldfirst = first;
      first = new Node();
      first.item = item;
      first.next = oldfirst;
   }

   public String pop()
   {
      String item = first.item;
      first = first.next;
      return item;
   }
}
```

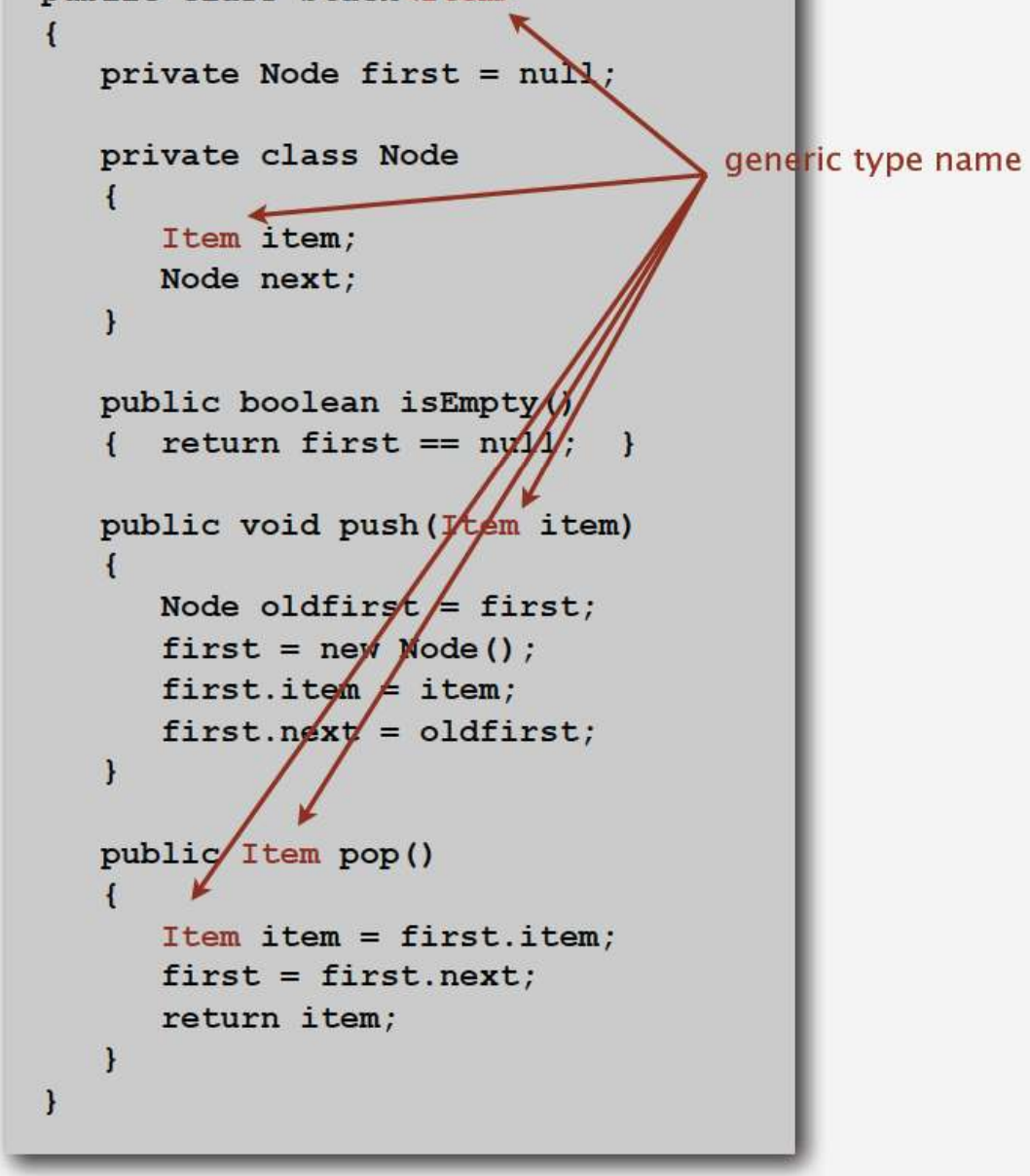
```
public class Stack<Item>
{
   private Node first = null;

   private class Node
   {
      Item item;
      Node next;
   }

   public boolean isEmpty()
   {  return first == null;  }

   public void push(Item item)
   {
      Node oldfirst = first;
      first = new Node();
      first.item = item;
      first.next = oldfirst;
   }

   public Item pop()
   {
      Item item = first.item;
      first = first.next;
      return item;
   }
}
```



Stack iterator: linked-list implementation

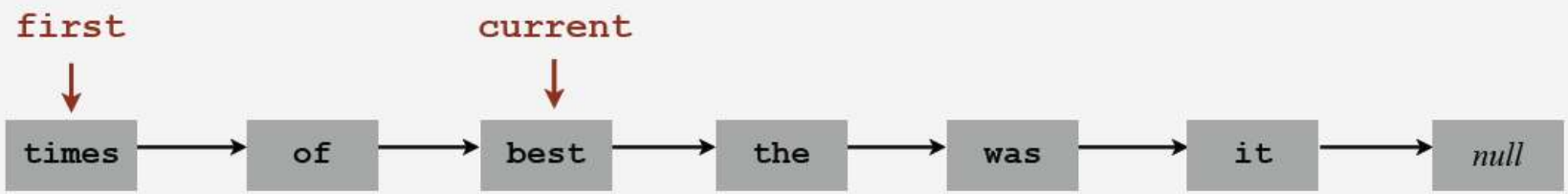
```
import java.util.Iterator;

public class Stack<Item> implements Iterable<Item>
{
    ...

    public Iterator<Item> iterator() { return new ListIterator(); }

    private class ListIterator implements Iterator<Item>
    {
        private Node current = first;

        public boolean hasNext() {  return current != null;  }
        public void remove()     {  /* not supported */      }
        public Item next()
        {
            Item item = current.item;
            current   = current.next;
            return item;
        }
    }
}
```



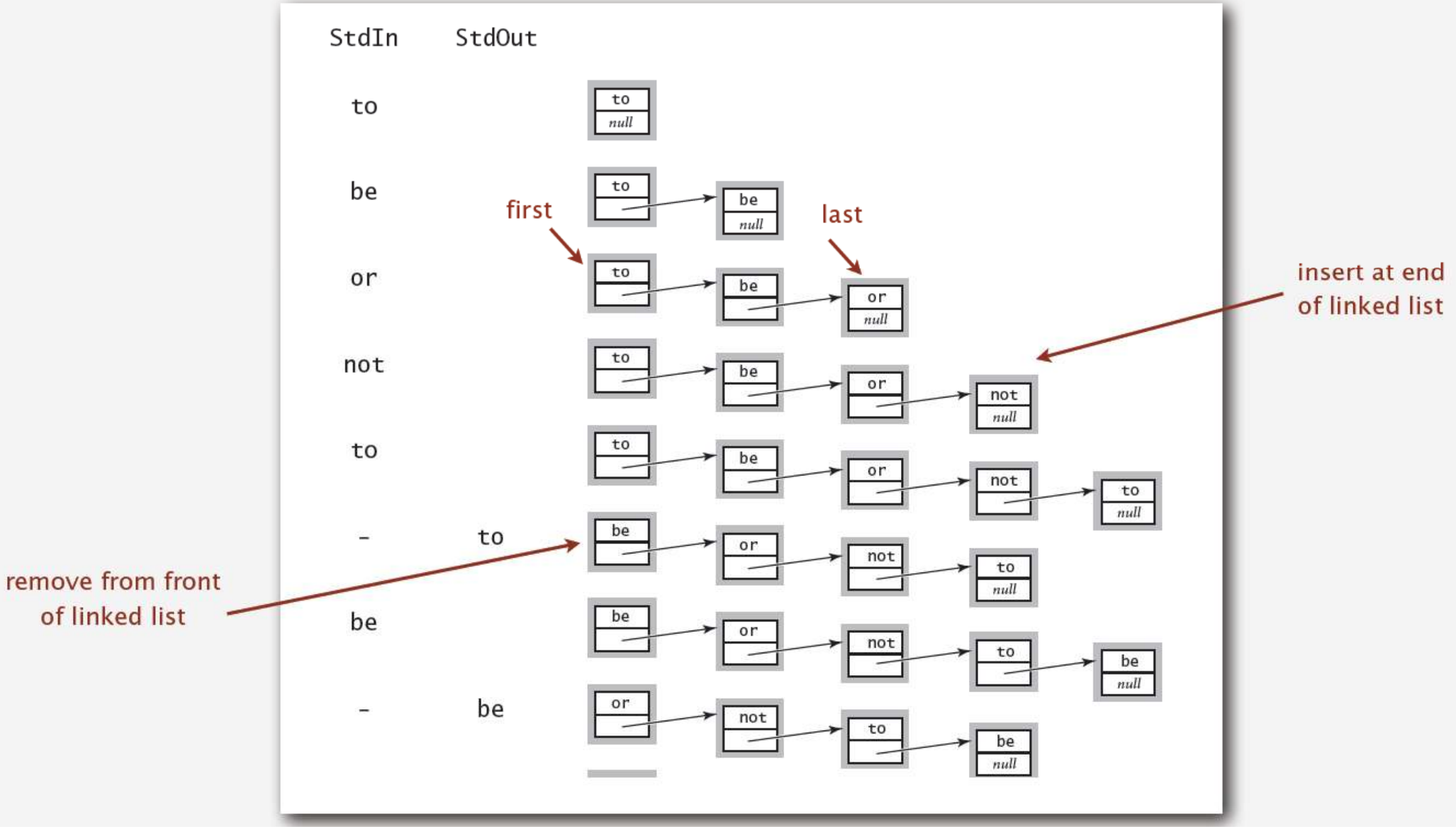
Linked list stack implementation performance

- Every operation takes constant time
- No array resizing cost

Queue: linked-list representation

Maintain pointer to first and last nodes in a linked list;

insert/remove from opposite ends.



Queue dequeue: linked-list implementation

inner class

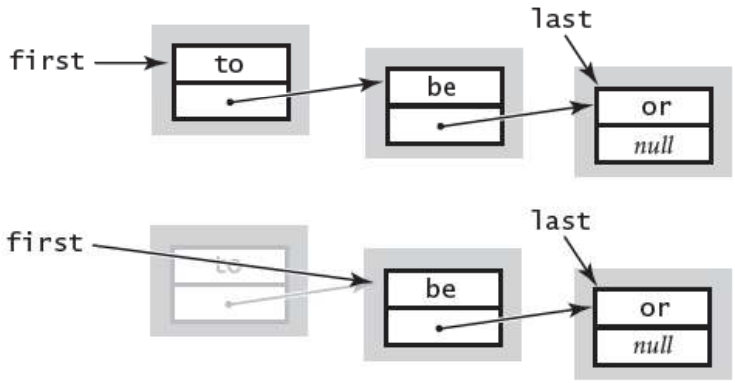
```
public class Node
{
   String item;
   Node next;
...
}
```

save item to return

```
String item = first.item;
```

delete first node

```
first = first.next;
```



return saved item

```
return item;
```

Remark. Identical code to linked-list stack `pop()`.

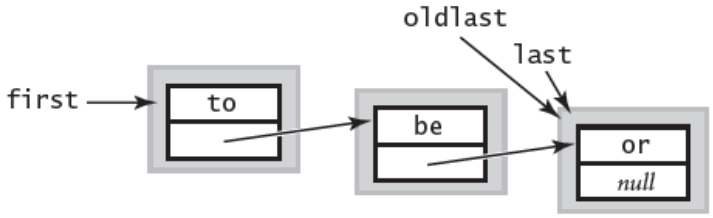
Queue enqueue: linked-list implementation

inner class

```
public class Node
{
   String item;
   Node next;
...
}
```

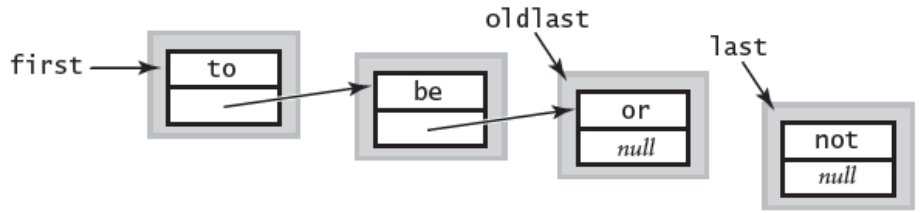
save a link to the last node

```
Node oldlast = last;
```



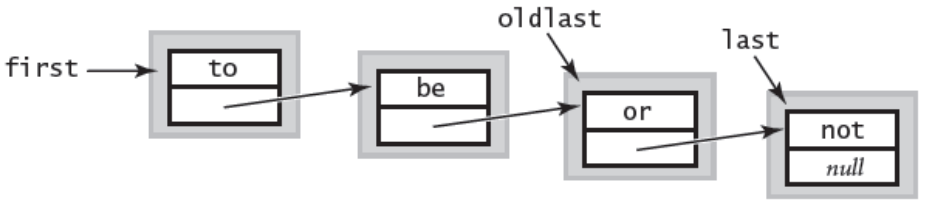
create a new node for the end

```
Node last = new Node();
last.item = "not";
last.next = null;
```



link the new node to the end of the list

```
oldlast.next = last;
```



Queue: linked-list implementation in Java

```
public class LinkedQueueOfStrings
{
   private Node first, last;

   private class Node
   {  /* same as in StackOfStrings */  }

   public boolean isEmpty()
   {  return first == null;  }

   public void enqueue(String item)
   {
      Node oldlast = last;
      last = new Node();
      last.item = item;
      last.next = null;
      if (isEmpty()) first = last;
      else           oldlast.next = last;
   }

   public String dequeue()
   {
      String item = first.item;
      first       = first.next;
      if (isEmpty()) last = null;
      return item;
   }
}
```