

Dynamic Data Structures

Wolfgang Schreiner

Research Institute for Symbolic Computation (RISC)

Johannes Kepler University, Linz, Austria

Wolfgang.Schreiner@risc.jku.at

<http://www.risc.jku.at>

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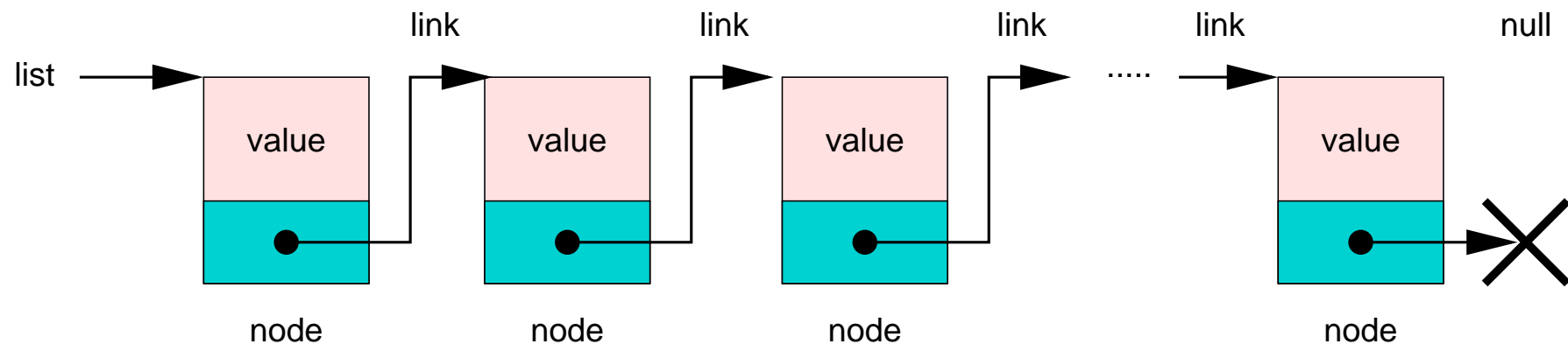
- Arrays have certain disadvantages as a data structure.
 - In an unordered array, searching is slow.
 - In an ordered array, inserting a new element is slow.
 - * All elements after the inserted element have to be shifted one position to the right.
 - In an ordered array, deleting an element is slow.
 - * All elements after the deleted element have to be shifted one position to the left.
 - The size of an array cannot be changed after creation.
- **Linked lists** solve some of these problems.
 - New elements can be easily inserted/deleted.
 - There is no a priori bound on number of elements that can be stored.
 - Linked lists are **not** used for fast searching.

Linked lists are another widely used data structure.

List Nodes

A linked list consists of nodes.

- A list **node** holds
 - a **value** of some type,
 - a **link**, i.e., a reference to another node of the list.



In Java, each list node is represented by an object.

Class Declaration

```
public class Node
{
    public int value; // value carried by node (any type possible)
    public Node next; // link to next node in list

    public Node(int value)
    {
        this.value = value;
    }

    public Node(int value, Node next)
    {
        this(value);
        this.next = next;
    }
}
```

Linking Nodes

- List [1] (single node holding the value 1).

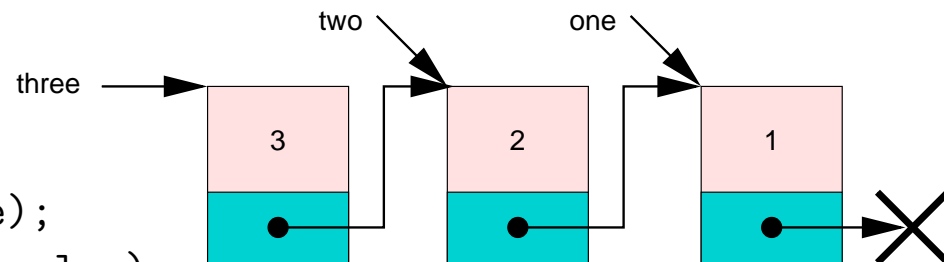
```
Node one = new Node(1);
System.out.println(one.value);
```

- List [2, 1]

```
Node two = new Node(2, one);
System.out.println(two.value);
System.out.println(two.next.value);
```

- List [3, 2, 1]

```
Node three = new Node(3, two);
System.out.println(three.value);
System.out.println(three.next.value);
System.out.println(three.next.next.value);
```



Updating Nodes

Different lists may have overlapping nodes.

- First node of **two** is second node of **three**.

```
two.value = -2;
```

```
System.out.println(three.next.value);
```

```
-2.
```

A list node may be referenced by multiple variables.

List Type

A list is an abstraction that is implemented by a sequence of nodes.

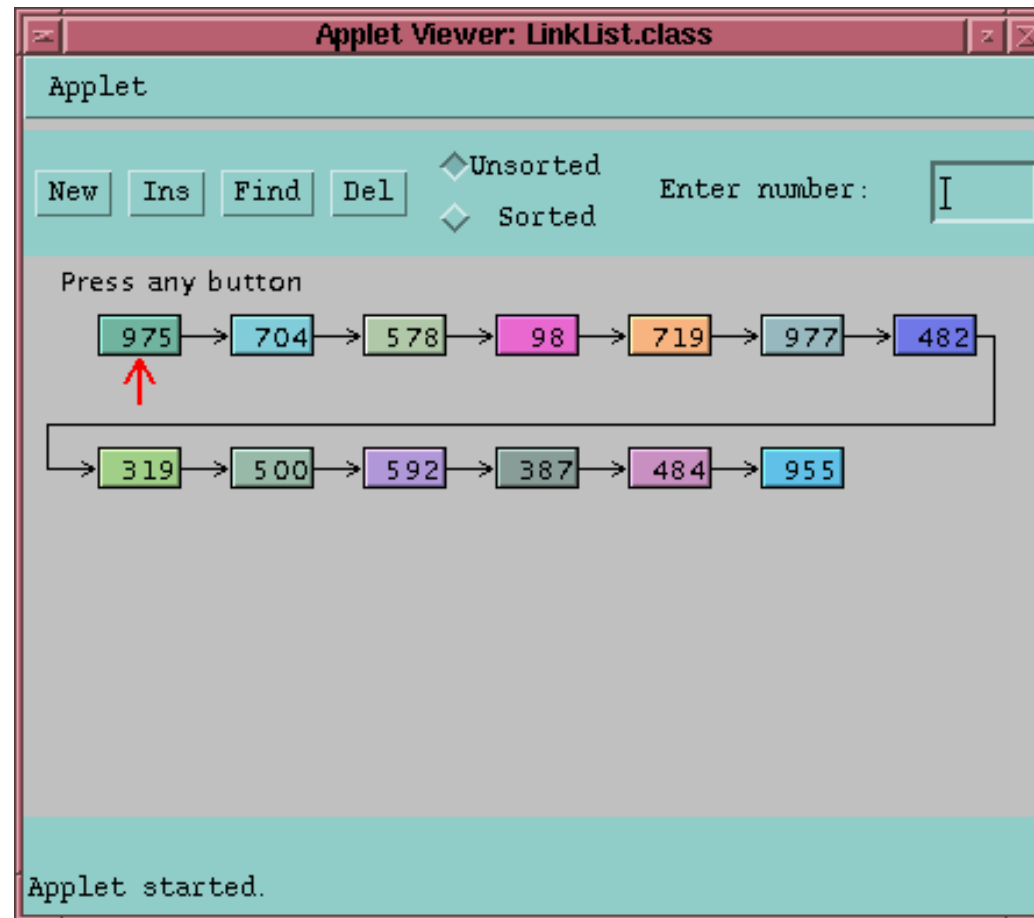
```
public class List
{
    public Node head; // reference to first node in list
    public List()
    {
    }
    ...
}
```

- Empty list:

```
List empty = new List()
```

We will now introduce various list operations.

Java Applet



Inserting List Elements

Insert an element at the head of a list.

```
public class List
{
    ...
    public void insert(int value)
    {
        Node node = new Node(value, head);
        head = node;
    }
}
```

```
List l = new List();
l.insert(1);
l.insert(2);
l.insert(3);
```

Inserting List Elements

It is more convenient to have a function that returns the new list.

```
// -----  
// list = insert(value)  
// 'list' is the result of inserting 'value' at the head of  
// 'this' list.  
// -----  
public List insert(int value)  
{  
    Node node = new Node(value, head);  
    head = node;  
    return this;  
}  
  
List l = new List();  
l.insert(1).insert(2).insert(3);
```

Searching for List Elements

```
// -----  
// node = search(value)  
// 'node' is the result of searching 'value' in 'this' list  
//  
// Output:  
//   all nodes referenced via 'this' remain unchanged.  
//   if 'node == null', then 'value' does not occur in 'this'  
//   if 'node != null', then 'node.value == value' and 'node'  
//     is the first node in 'this' for which this holds.  
// -----  
public Node search(int value)
```

Searching for List Elements

```
public Node search(int value)
{
    Node node = head;
    while (node != null && node.value != value)
        node = node.next;
    return node;
}
```

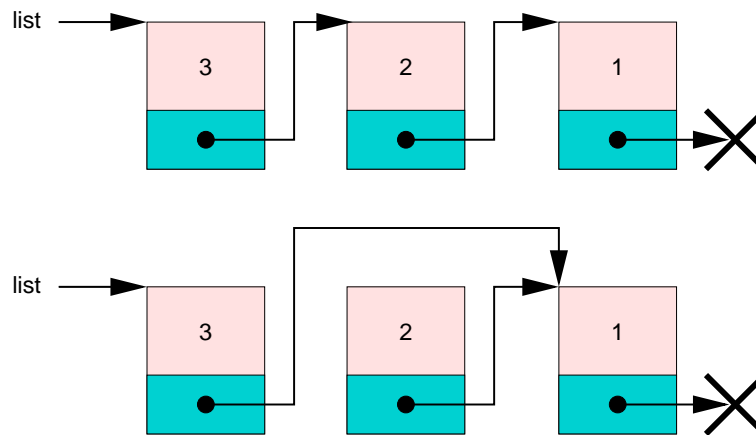
```
public Node search(int value)
{
    for (Node node = head; node != null; node = node.next)
        if (node.value == value) return node;
    return null;
}
```

Similar to searching in an unsorted array.

Deleting List Elements

Delete from list first node that holds a particular key value.

- Find appropriate list node and update any reference to this node:
 - If the deleted node was the first node, *head* has to be updated.
 - If the deleted node was not the first node, the link of the predecessor node has to be updated.
 - Updated reference points to the successor of the deleted node.
- Example: delete value 2 from list [3, 2, 1].



Specification of Method

```
// -----  
// list = delete(value)  
// 'list' is the result of deleting the first node that  
// holds 'value' from 'this' list.  
//  
// Output  
// 'list == this'.  
// if 'value' was not in the old 'this', 'this' equals  
// the old 'this'.  
// if 'value' was in the old 'this', 'this' equals the  
// old 'this' except that the first node with  
// 'node.value == value' is unlinked.  
// -----  
List delete(int value);
```

Implementation of Method

```
public List delete(int value)
{
    Node prev = null; // previous node
    Node node = head; // current node
    while (node != null && node.value != value)
    {
        prev = node;
        node = node.next;
    }
    if (node != null)
    {
        if (prev == null)
            head = node.next;
        else
            prev.next = node.next;
    }
    return this;
}
```

Usage of Method

Method `delete` has been implemented as a function.

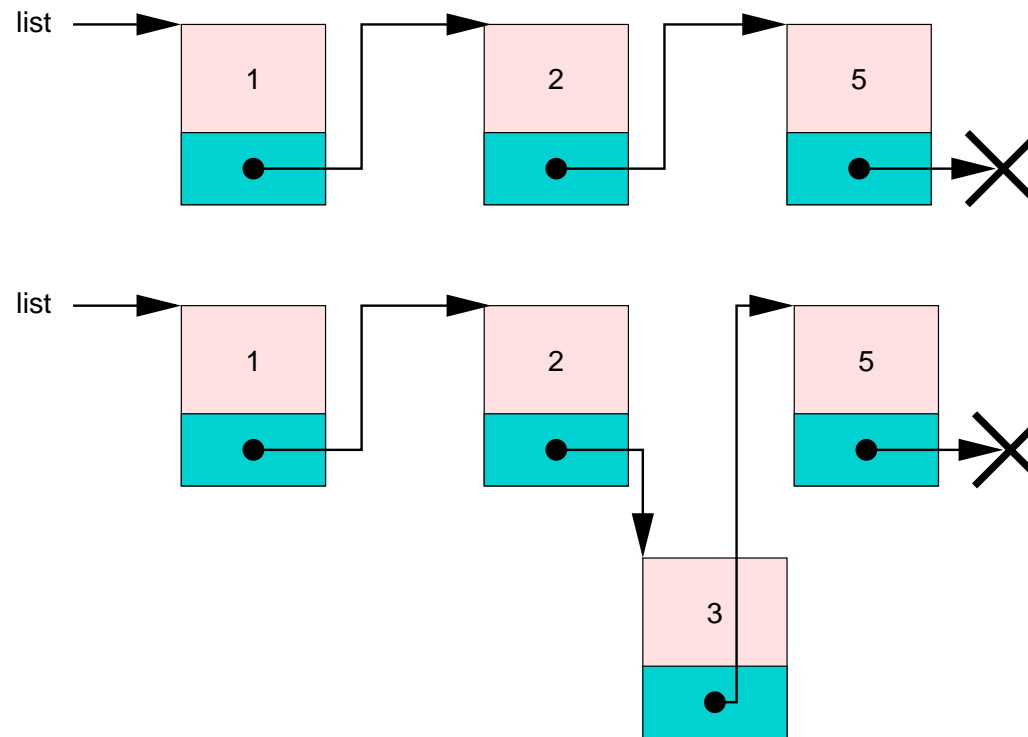
```
List l = new List();  
l.insert(1).insert(2).insert(1).delete(1).delete(2).delete(2);
```

Convenient form of list manipulation.

Keeping a List Sorted

Insert new elements such that key values are ordered.

- Example: insert value 3 in list $[1, 2, 5]$ giving list $[1, 2, 3, 5]$.



Specification of Method

```
// -----  
// list = insertSorted(value)  
// 'list' is the result of inserting 'value' into  
// the sorted 'this' list.  
//  
// Input  
//   'this' is sorted.  
// Output  
//   'list == this' and 'this' is sorted.  
//   'this' is the same as the old 'this' except that  
//     a new node with 'value' has been inserted.  
// -----
```

Implementation of Method

```
public List insertSorted(int value)
{
    Node prev = null; // previous node
    Node node = head; // current node
    while (node != null && node.value < value)
    {
        prev = node;
        node = node.next;
    }
    Node n = new Node(value, node);
    if (prev == null)
        head = n;
    else
        prev.next = n;
    return this;
}
```

Searching in Sorted Lists

```
// -----  
// node = search(value)  
// 'node' is the result of searching 'value' in 'this' list  
//  
// Input: 'this' list is sorted in ascending order.  
// Output: ... (as before)  
// -----  
public Node search(int value)  
{  
    for (Node node = head; node != null; node = node.next)  
    {  
        if (node.value == value) return node;  
        if (node.value > value) return null;  
    }  
    return null;  
}
```