Data Structures and Algorithms

Chapter 3

Linked Lists

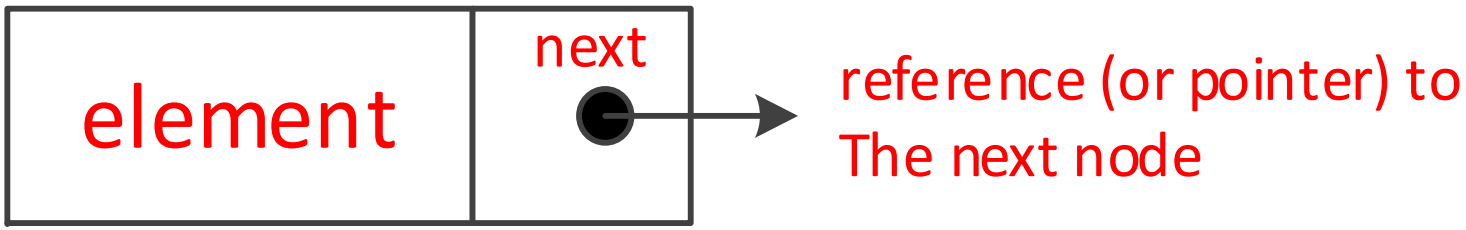
- A node stores an element and a link (or links).
- Nodes are connected by links.
- A link is the reference to (or the address of) a node.
- Singly linked list, doubly linked list, circularly linked list
- *Link*, *reference*, and *pointer* are used interchangeably.

Linked Lists

- Need to learn
  - Different linked data structures
  - To write code creating and manipulating linked data structures.
  - To use predefined linked data structures, such as Java's *LinkedList*

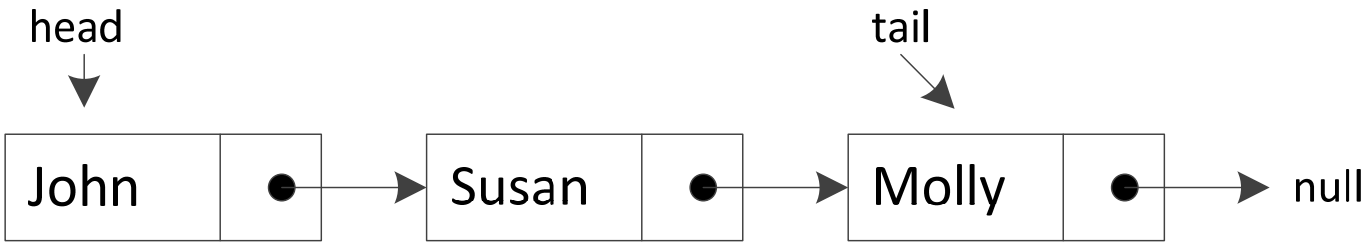
Singly Linked Lists

- Nodes are connected by a single link.
- A link points to (or references) the next node.
- A node has *element* and the reference (or pointer) to the next node.



Singly Linked Lists

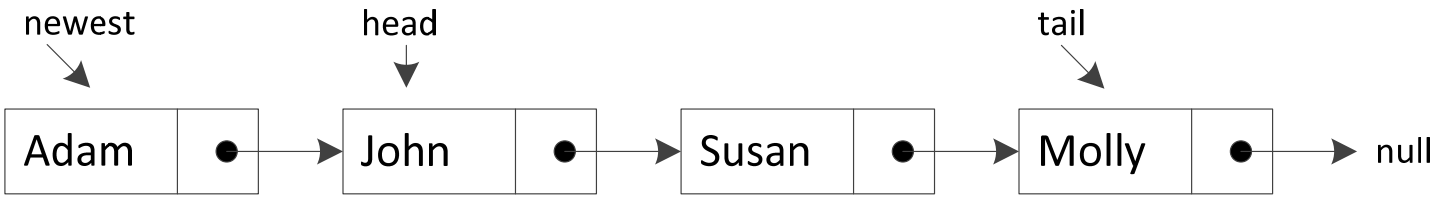
- We usually keep two references, *head* and *tail*, for a singly linked list.



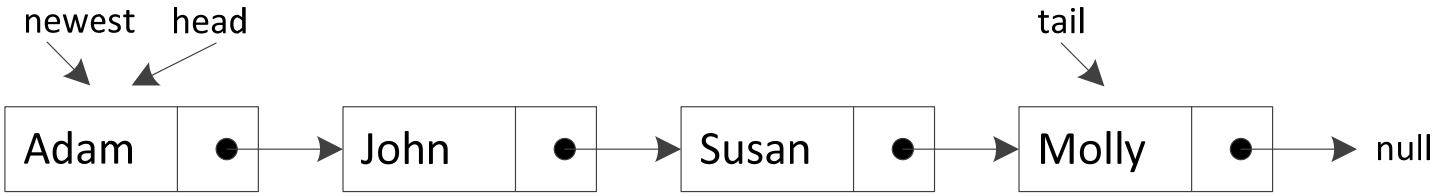
Singly Linked Lists

- Add a node to the head of a list

  newest = Node(“Adam”); newest.next = head;



head = newest;



Singly Linked Lists

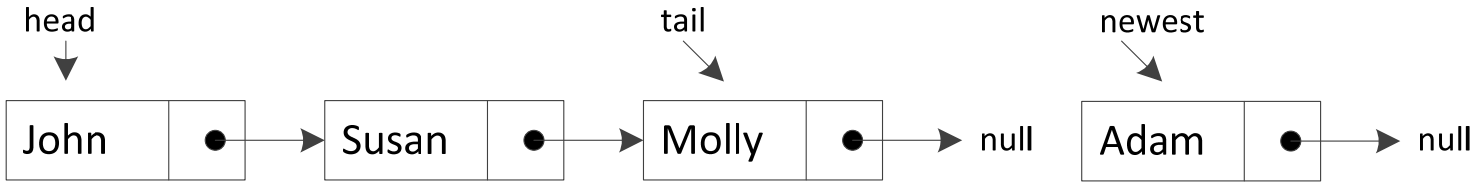
- Add a node to the head of a list

Algorithm addFirst(*e*)
    newest = Node(e) // new node with element *e*
    newest.next = head // new node's next is set to refer
                       // to current head node
    head = newest // new head refers to new node
    size = size + 1 // list size (node count) is
                     // incremented

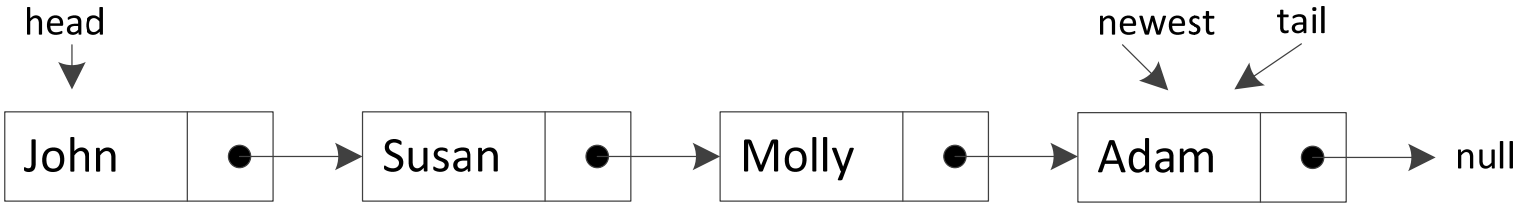
Singly Linked Lists

- Add a node to the tail of a list

newest = Node(“Adam”); newest.next = null ;



tail.next = newest; tail = newest;



Singly Linked Lists

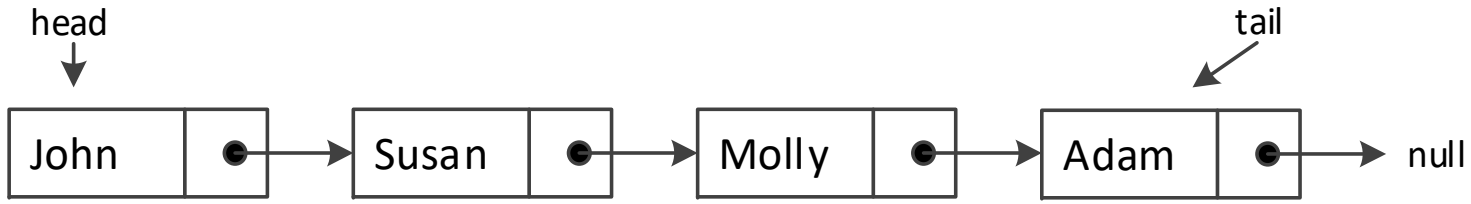
- Add a node to the tail of a list

  Algorithm addLast(*e*)

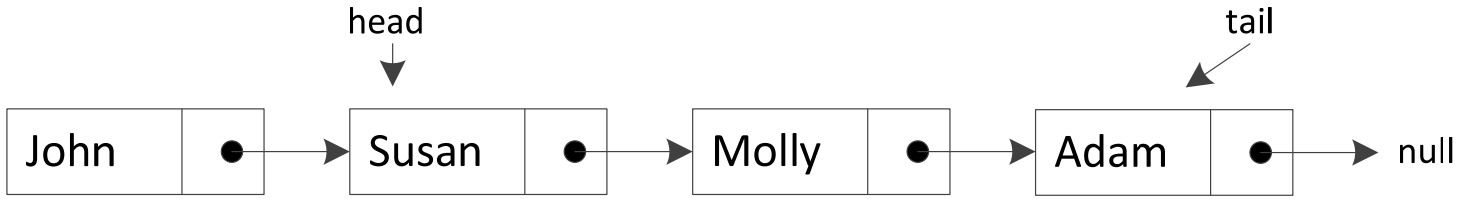
  ```
  newest = Node(e)    // new node with element e
  newest.next = null   // new node's next is set to null
  tail.next = newest // current tail node's next points to
                       // new node
  tail = newest       // new tail points to new node
  size = size + 1     // list size (node count) is
                      // incremented
  ```

Singly Linked Lists

- Removing an arbitrary node: nontrivial and inefficient.
- Removing a node from the head of a list



head = head.next;



Singly Linked Lists

```
Algorithm removeFirst( )
    if head == null
        the list is empty
    head = head.next   // new head points to next node
    size = size - 1    // list size (node count) is
                       // decremented
```

Singly Linked Lists

- Generic *Node* class in *SinglyLinkedList* class

```
1  private static class Node<E> {
2      private E element;
3      private Node<E> next;
4      public Node(E e, Node<E> n) {
5          element = e;
6          next = n;
7      }
8     public E getElement() { return element; }
9     public Node<E> getNext() { return next; }
10    public void setNext(Node<E> n) { next = n; }
11 }
```

Singly Linked Lists

- Instance variables of *SinglyLinkedList* class

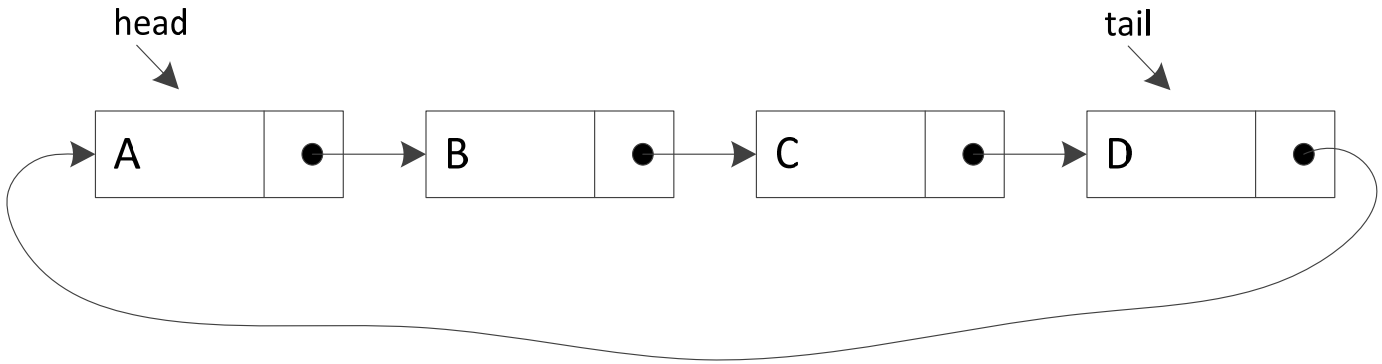
```
public class SinglyLinkedList<E> implements Cloneable
{
    // nested class Node
    protected Node<E> head = null;
    protected Node<E> tail = null;
    protected int size = 0;
    // constructors and methods
```

Singly Linked Lists

- Complete code of *SinglyLinkedList.java*

Circularly Linked Lists

- A singly linked list where the last element is connect to the first element, forming a circle.
- Used in application where objects are manipulated in a round-robin manner, such as process scheduling.



- Don’t need to keep the *head* reference.

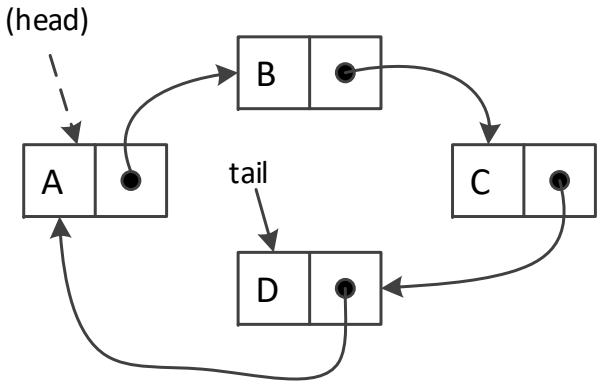
Circularly Linked Lists

- Round-robin process scheduling: Processes are executed by CPU one at a time for a *slice* of time.

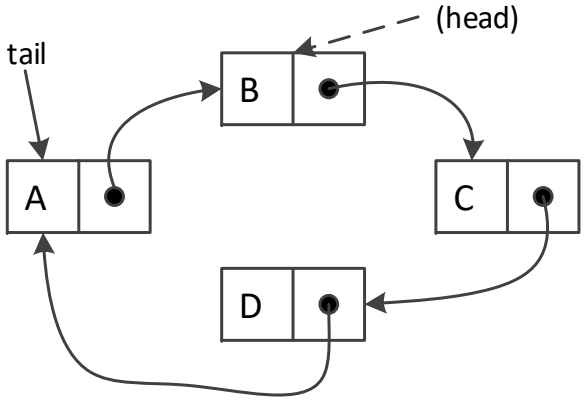
```
// C is a circularly linked list
Give a time slice to C.first()
C.rotate()
```

Circularly Linked Lists

- Rotate operation



Before rotation

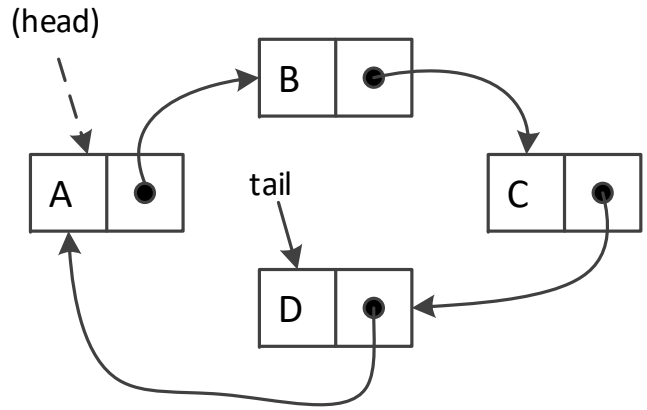


After rotation

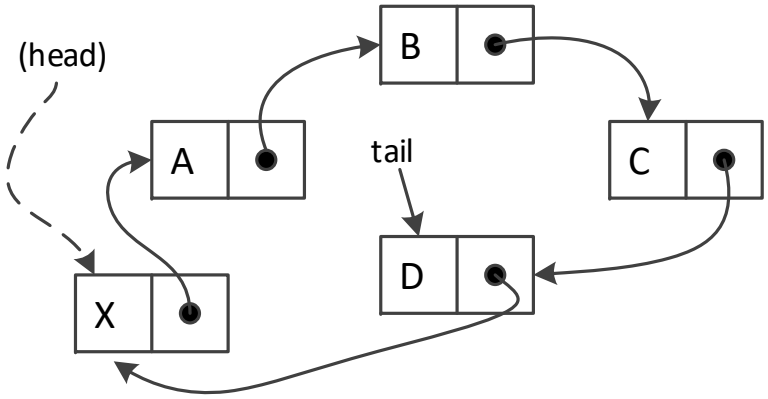
```
public void rotate() {          // rotate the first element to the back of the
list
    if (tail != null)           // if empty, do nothing
      tail = tail.getNext();    // the old head becomes the new tail
  }
```

Circularly Linked Lists

- Add a node to before head (this is the same as adding a node after tail)



Before insertion



After insertion

Circularly Linked Lists

- Can reuse most of *SinglyLinkedList* code.
- The *addFirst* method is modified

```
public void addFirst(E e) {     // adds element e to the front of the list
    if (size == 0) {
      tail = new Node<>(e, null);
      tail.setNext(tail);                  // link to itself circularly
    } else {
      Node<E> newest = new Node<>(e, tail.getNext());
      tail.setNext(newest);
    }
    size++;
  }
```

Doubly Linked Lists

- Singly linked list:
  - Not easy to insert a node at an arbitrary position.
  - Nontrivial to delete a node from an arbitrary position.

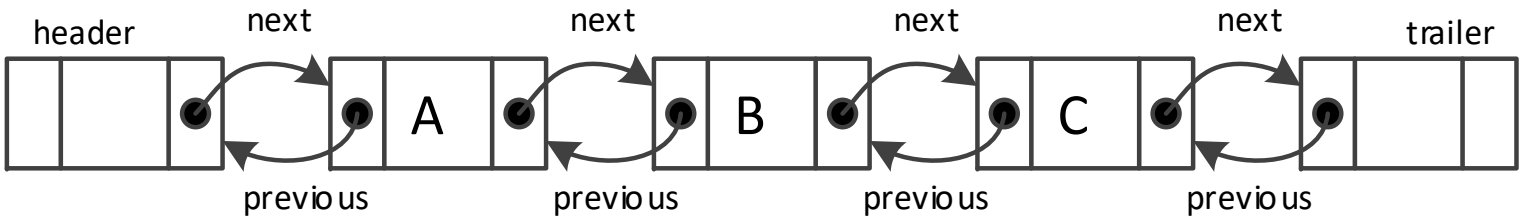
- These operations, however, can be performed relatively efficiently with doubly linked lists.

Doubly Linked Lists

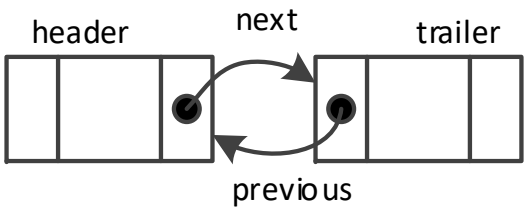
- A node has two pointers.
- *previous* points to the previous node.
- *next* points to the next node.

Doubly Linked Lists

- Doubly linked list example

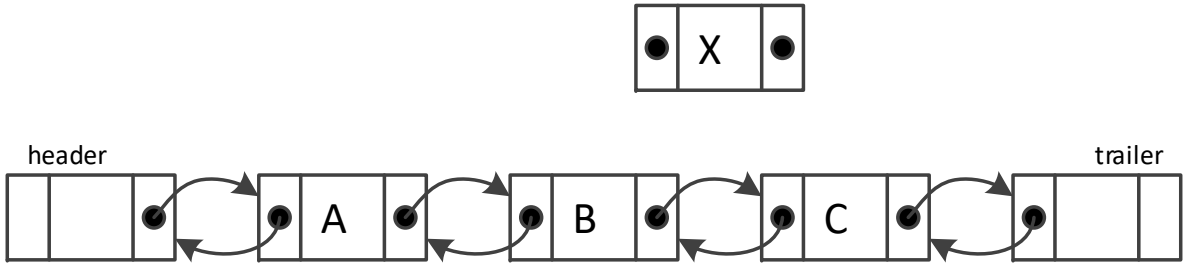


- An empty list

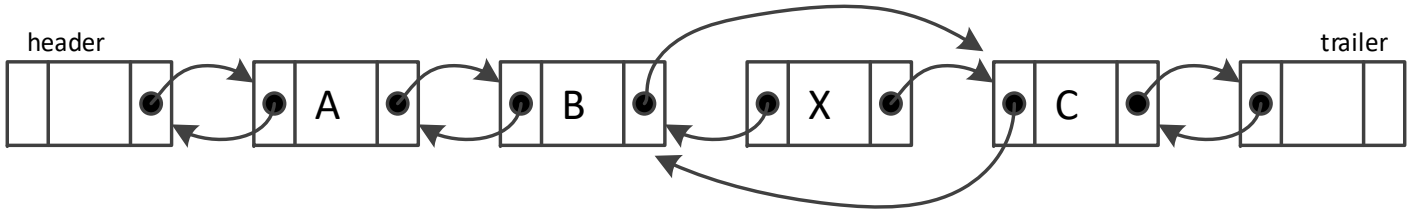


Doubly Linked Lists

- Insert a new node X between B and C

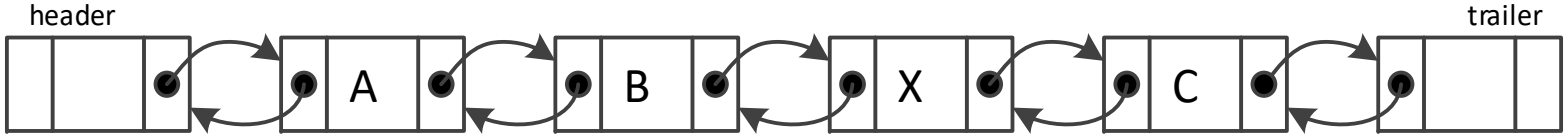


- The previous reference of X are set to point to B.
- The next reference of X are set to point to C.



Doubly Linked Lists

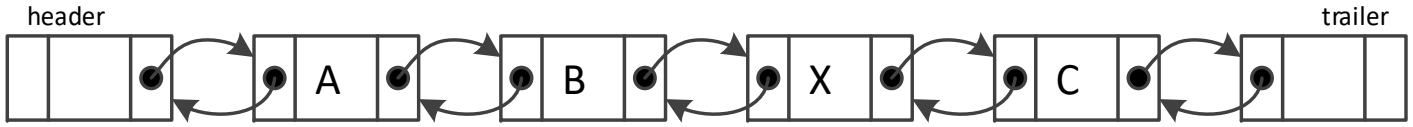
- The next reference of B and the previous reference of C are updated to point to X.



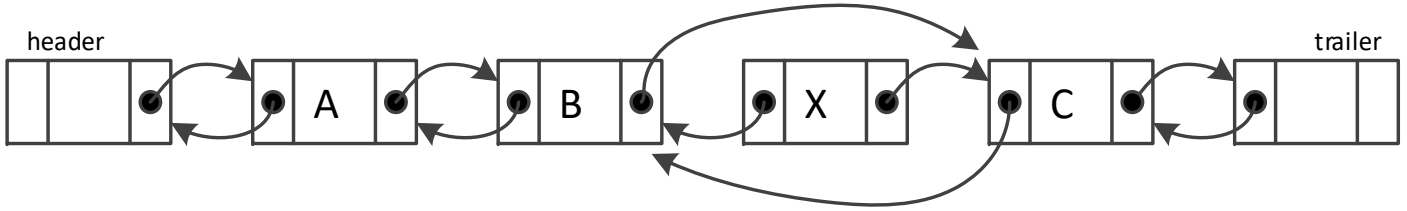

```
1   private void addBetween(E e, Node<E> predecessor,
                                    Node<E> successor)  {
2   Node<E> newest = new Node<>(e, predecessor, successor);
3   predecessor.setNext(newest);
4   successor.setPrev(newest);
5   size++;
6  }
```

Doubly Linked Lists

- Delete X

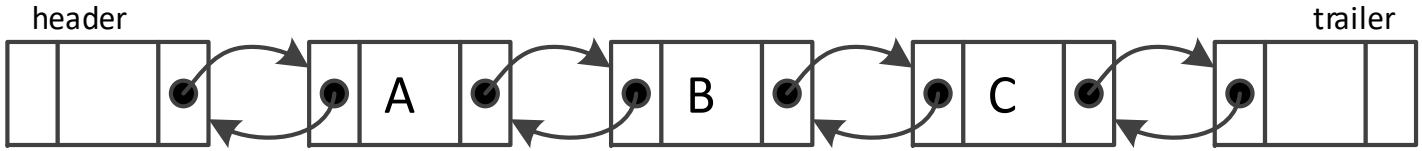


- Set the next reference of B to point to C
- Set the previous reference of C to point to B.



Doubly Linked Lists

- X is not a part of the list any more. The updated list is:




```
1  private E remove(Node<E> node) {
2      Node<E> predecessor = node.getPrev();
3      Node<E> successor = node.getNext();
4      predecessor.setNext(successor);
5      successor.setPrev(predecessor);
6      size--;
7      return node.getElement();
8  }
```

Doubly Linked Lists

- A complete code of *DoublyLinkedList.java*

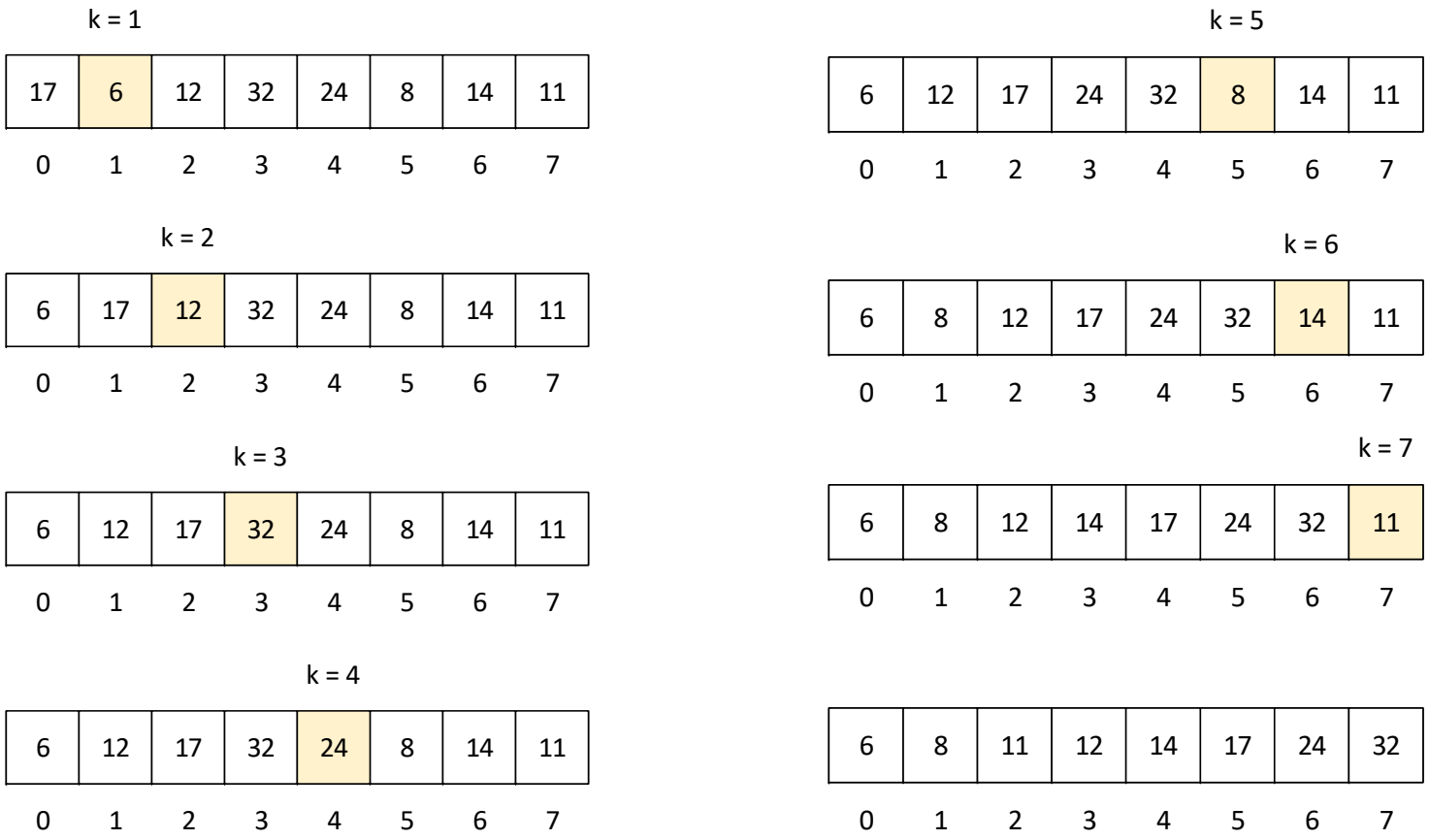
Insertion Sort

- There are different sorting algorithms.
- Will discuss insertion sort algorithm (on an array).
- Pseudocode

Algorithm InsertionSort(*A*)
    Input: Array *A* of *n* comparable elements
    Output: Array *A* with elements rearranged in
            nondecreasing order
    for *k* from 1 to *n* – 1**do**
        Insert *A*[*k*] at its proper location within *A*[0 .. *k*]

Insertion Sort

- Illustration



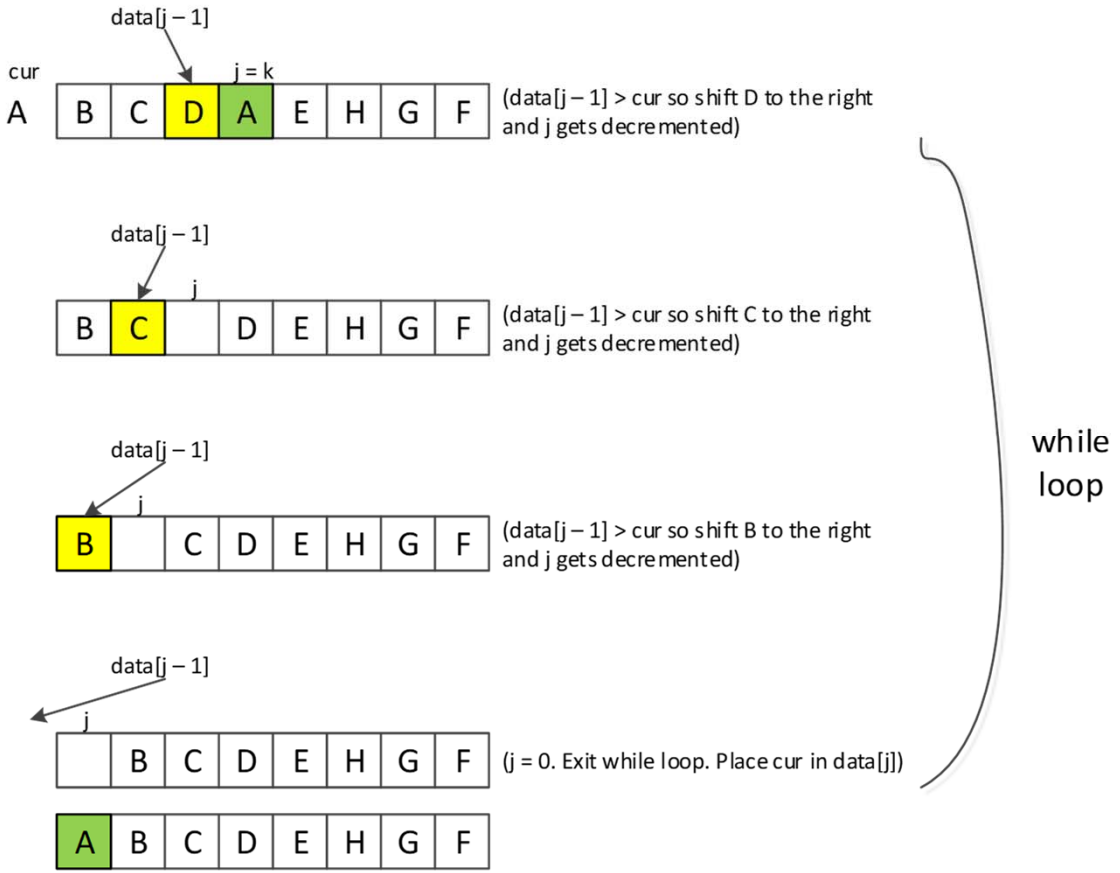
Insertion Sort

- Java implementation

```
1  public class InsertionSort {
2    public static void insertionSort(char[ ] data) {
3      int n = data.length;
4      for (int k = 1; k < n; k++) {    // begin with second element
5          char cur = data[k];              // save data[k] in cur
6          int j = k;                       // find correct index j for cur
7          while (j > 0 && data[j-1] > cur) {  // thus, data[j-1] must go after cur
8              data[j] = data[j-1];                    // shift data[j-1] rightward
9              j--;                                    // and consider previous j for cur
10         } // while
11         data[j] = cur;                    // this is the proper place for cur
12     } // for
13 }                                        // running time: O(n^2)
```

Insertion Sort

- Illustration of while loop in Java implementation



Testing Equality

- When comparing two reference variables, there are two notions of equivalence.
- First interpretation: Test whether two reference variables are pointing to the same object.
- Second interpretation: Test whether the contents of the two objects pointed to by the references are the same.

```
String s1 = new String("data structure");
String s2 = new String("data structure");
```

- Is s1 equal to s2?
  - No, by the first interpretation
  - Yes, by the second interpretation

Testing Equality

- In Java, you can compare with “==“ operator or using the *equals* method.
- “==“ compares the values of the reference variables, i.e., it checks whether they refer to the same object.
- The *equals* method is defined in the *Object* class, and, as it is, it is effectively the same as “==“ operator.
- To implement the “second interpretation” for objects of a class, the class must define its own *equals* method tailored for the objects of that class.

Testing Equality

- String class has *equals* method which performs character-by-character, pair-wise comparison.

```
1  public class StringTest {
2      public static void main(String[] args) {
3          String s1 = new String("data structure");
4          String s2 = s1;
5          String s3 = new String("data structure");
6          System.out.println("reference s1 equals reference s2: " + (s1 == s2));
7          System.out.println("reference s1 equals reference s3: " + (s1 == s3));
8          System.out.println("string s1 equals string s3: " + s1.equals(s3));
10     }
11 }
```

- Output: true, false, true

Testing Equality

- Equivalence testing with arrays
  - a == b: Tests if a and b refer to the same array instance.
  - a.equals(b): This is identical to a == b.
  - Arrays.equals(a, b): Returns true if the arrays have the same number of elements and all pairs of corresponding elements are equal to each other. If elements are primitives, == operator is used. If elements are reference types, then *a*[*k*].*equals*(*b*[*k*]) is used.

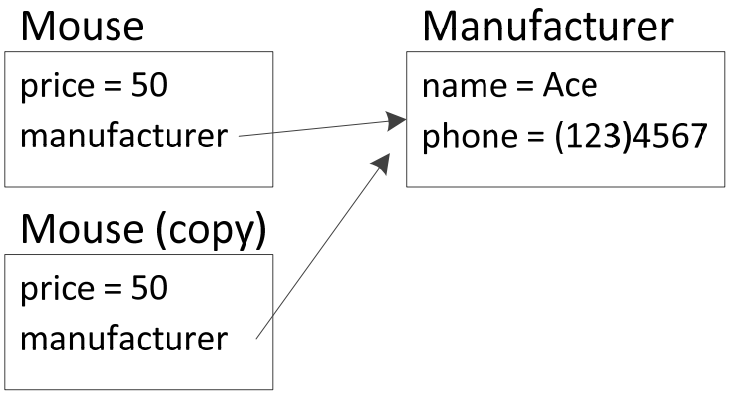
Testing Equality

- Equivalence testing with linked lists
  - Traverse two lists and compare pairs of corresponding elements.
  - Refer to the *equals* method in the *SinglyLinkedList* class.

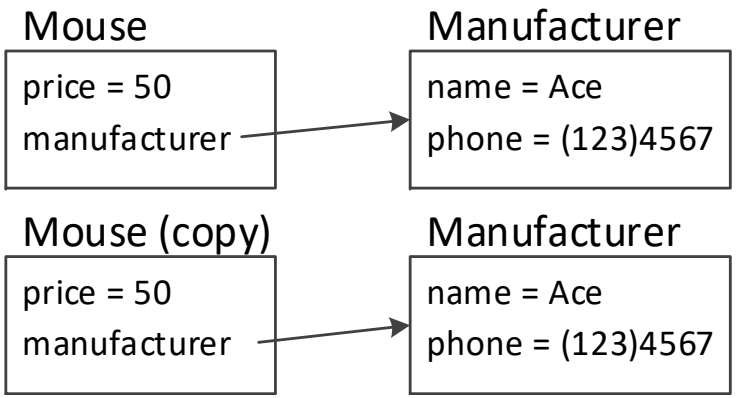
Cloning Data Structures

- Shallow copy vs. deep copy

Shallow copy



Deep copy



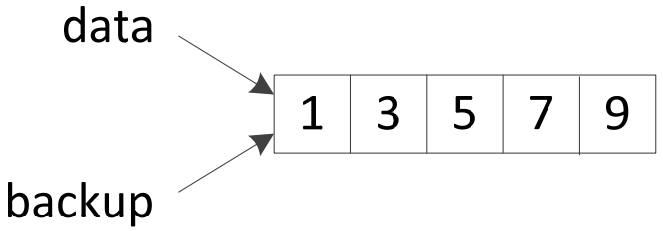
Cloning Data Structures

- Java's Object class has the *clone* method.
- This clone method creates a shallow copy.
- If necessary, each class must define its own clone method.

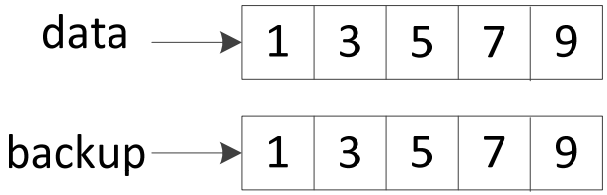
Cloning Data Structures

- Cloning arrays with elements of primitive type

```
int[ ] data = {1,3,5,7,9};
int[ ] backup;
backup = data;
```



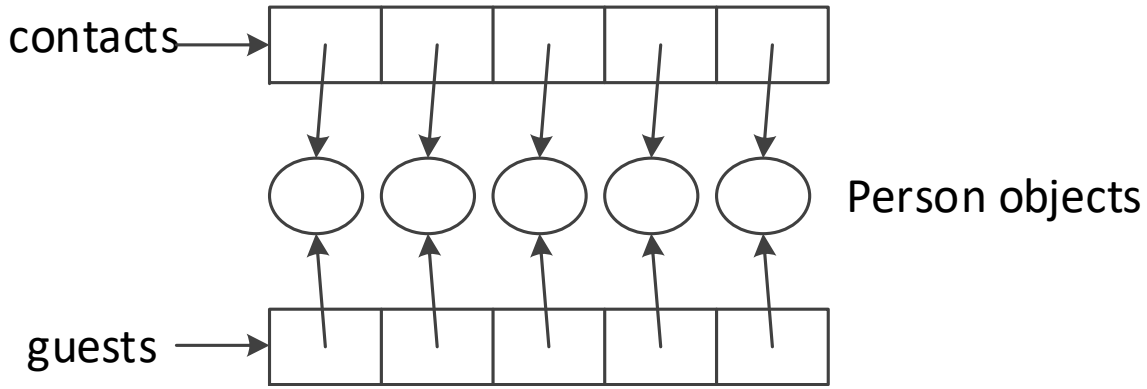

```
backup = data.clone();
```



Cloning Data Structures

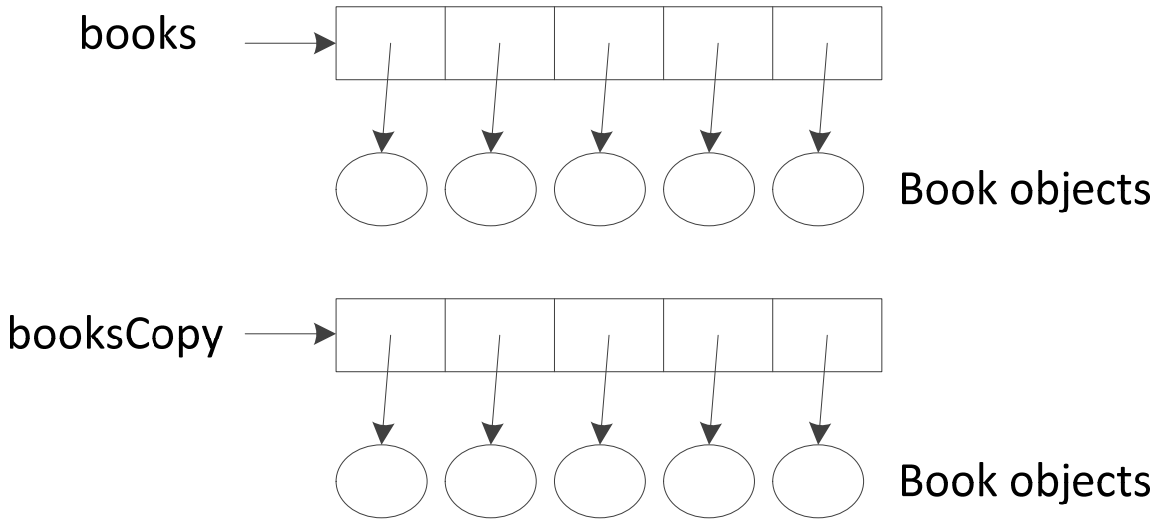
- Cloning arrays with elements of object type

guests = contacts.clone( ); // a shallow copy is created



Cloning Data Structures

- Cloning arrays with elements of object type
  - The following is a deep copy.
  - A separate code must be written.



Cloning Data Structures

- Cloning linked lists:
  - Must copy one node at a time.
  - Refer to the *clone* method in *SinglyLinkedList* class.

References

- M.T. Goodrich, R. Tamassia, and M.H. Goldwasser, “Data Structures and Algorithms in Java,” Sixth Edition, Wiley, 2014.