Lecture 11: Java Collections Framework

Chapter outline

- Lists
  - Collections
  - `LinkedList` vs. `ArrayList`
  - Iterators
- Sets
  - `TreeSet` vs. `HashSet`
  - Set operations
- Maps
  - Map operations
  - Map views
  - `TreeMap` vs. `HashMap`

Lists

reading: 11.1

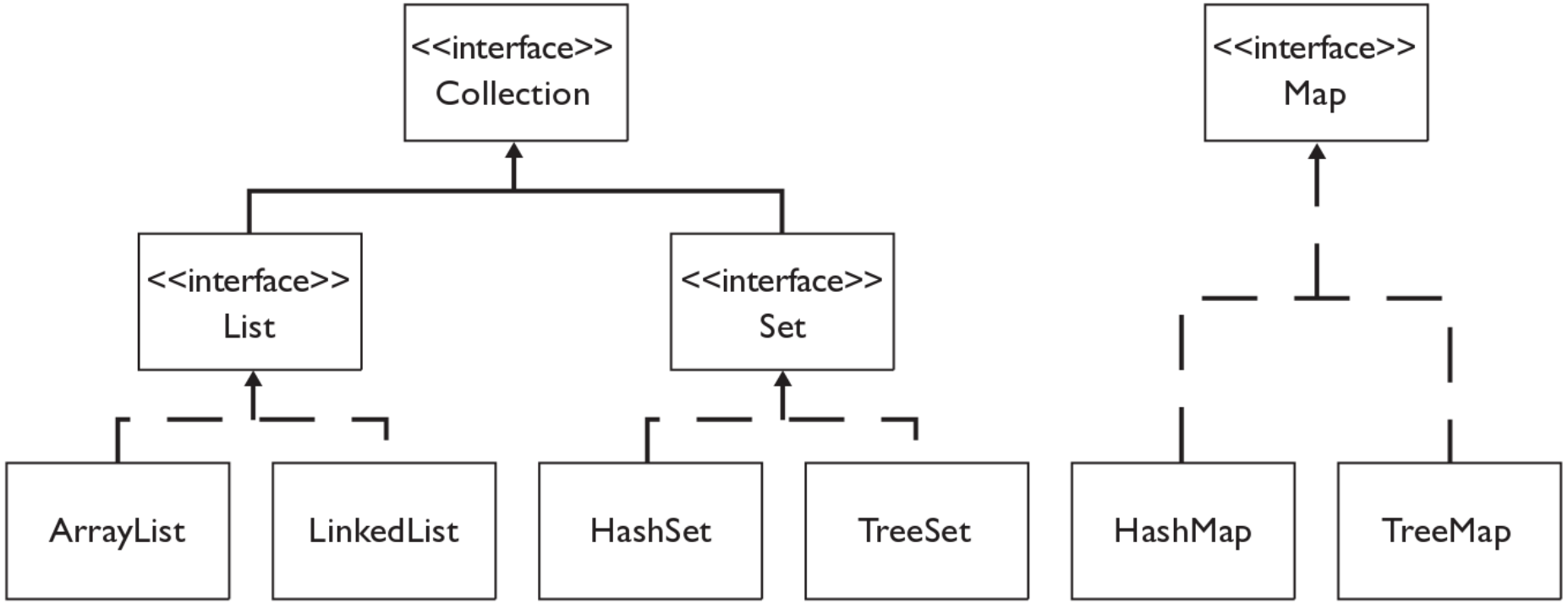
Collections

- **collection**: an object that stores data inside it
  - the objects stored are called **elements**
  - some collections maintain an ordering, some don't
  - some collections allow duplicates, some don't
  - an array is like a very crude "collection"

  - typical operations:
    - add element, remove element, clear all elements, contains or find element, get size
  - most collections are built with particular kinds of data, or particular operations on that data, in mind

  - examples of collections:
    - list, bag, stack, queue, set, map, graph

Java collections framework



Java's `Collection` interface

- The interface `Collection<E>` in `java.util` represents many kinds of collections.
  - Every collection has the following methods:

Method name	Description
`add(`*value*`)`	adds the given value to the collection
`addAll(`*collection*`)`	adds all elements from given collection to this one
`clear()`	removes all elements
`contains(`*value*`)`	returns `true` if the element is in the collection
`containsAll(`*collection*`)`	`true` if this collection contains all elements from the other
`isEmpty()`	`true` if the collection does not contain any elements
`removeAll(`*collection*`)`	removes all values contained in the given collection from this collection
`retainAll(`*collection*`)`	removes all values not contained in the given collection from this collection
`size()`	returns the number of elements in the list
`toArray()`	returns an array containing the elements of this collection

`Collection` interface,cont'd.

- `public boolean isEmpty()`
  Returns true if this list contains no elements.

- `public Iterator<E> iterator()`
  Returns a special object for examining the elements of the list in order (seen later).

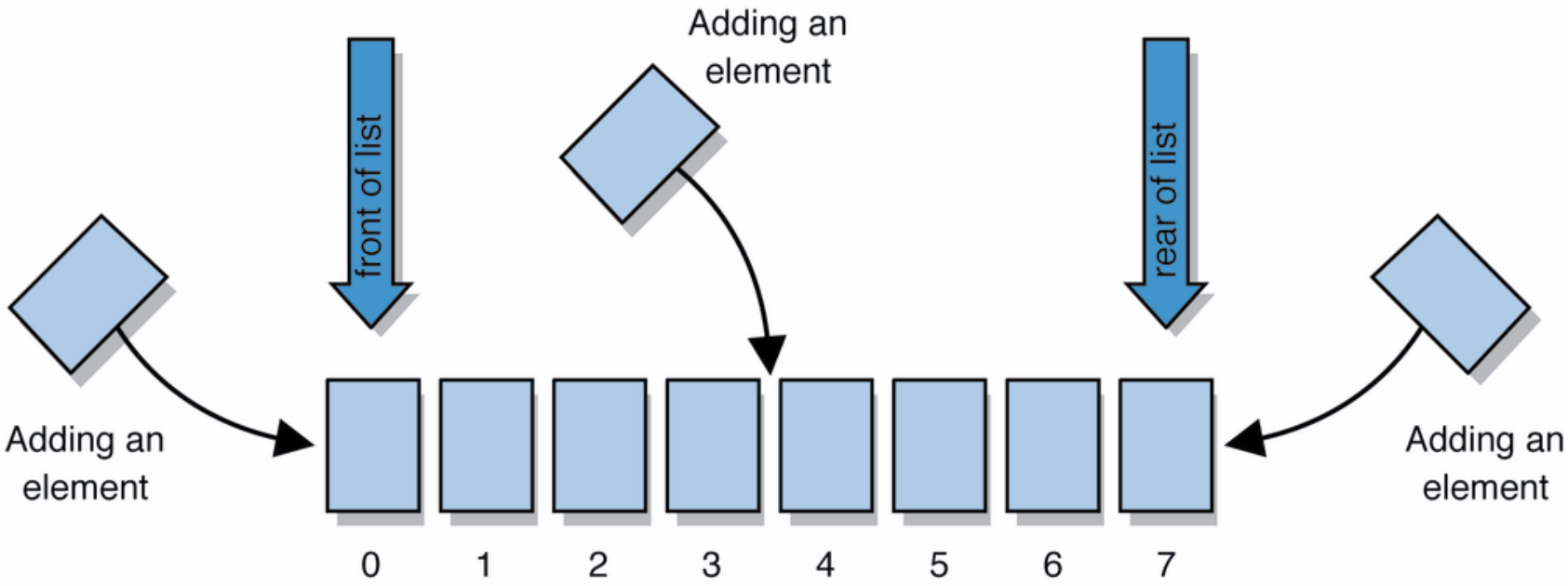
- `public boolean remove(Object o)`
  Removes the first occurrence in this list of the specified element.

- `public int size()`
  Returns the number of elements in this list.

- `public Object[] toArray()`
  Returns an array containing all of the elements from this list.

An example collection: List

- **list**: an ordered sequence of elements, each accessible by a 0-based index
  - one of the most basic collections



List features

- Maintains elements in the order they were added (new elements are added to the end by default)
- Duplicates are allowed
- Operations:
  - add element to end of list
  - insert element at given index
  - clear all elements
  - search for element
  - get element at given index
  - remove element at given index
  - get size
    - some of these operations are inefficient (seen later)

- The list manages its own size; the user of the list does not need to worry about overfilling it.

Java's `List` interface

- Java also has an interface `List<E>` to represent a list of objects.
  - It adds the following methods to those in `Collection<E>`:
    (a partial list)

- `public void add(int index, E element)`
  Inserts the specified element at the specified position in this list.

- `public E get(int index)`
  Returns the element at the specified position in this list.

- `public int indexOf(Object o)`
  Returns the index in this list of the first occurrence of the specified element, or `-1` if the list does not contain it.

`List` interface, cont'd.

- `public int lastIndexOf(Object o)`
  Returns the index in this list of the last occurrence of the specified element, or -1 if the list does not contain it.

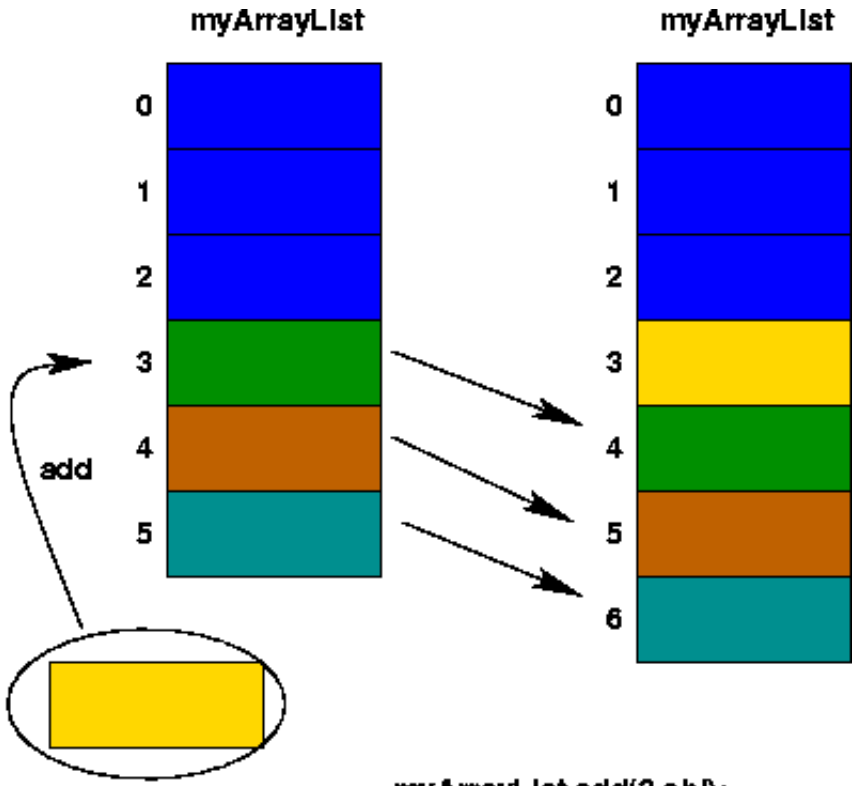
- `public E remove(int index)`
  Removes the object at the specified position in this list.

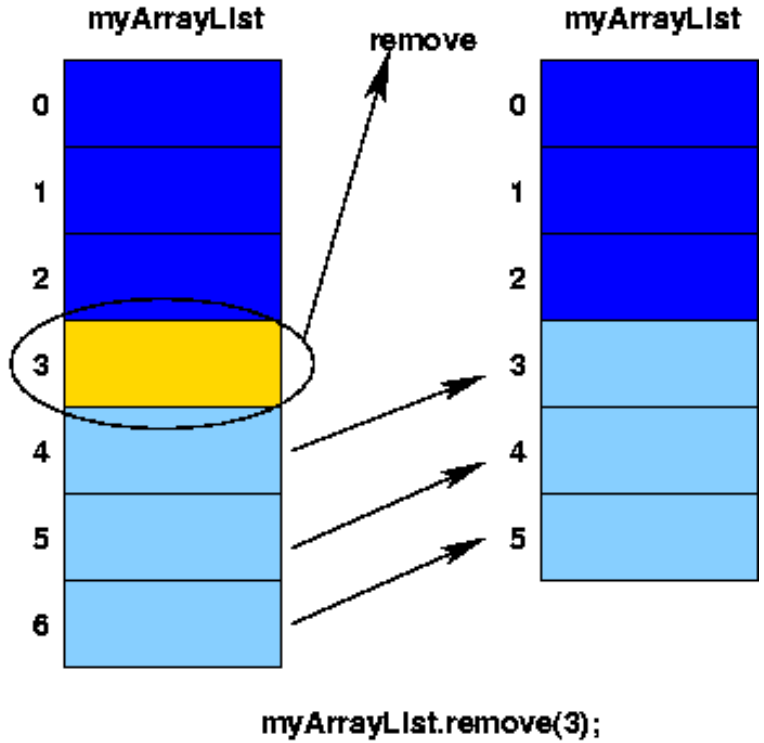
- `public Object set(int index, E element)`
  Replaces the element at the specified position in this list with the specified element.

- Notice that the methods added to `Collection<E>` by `List<E>` all deal with indexes
  - a list has indexes while a general collection may not

Array list limitations

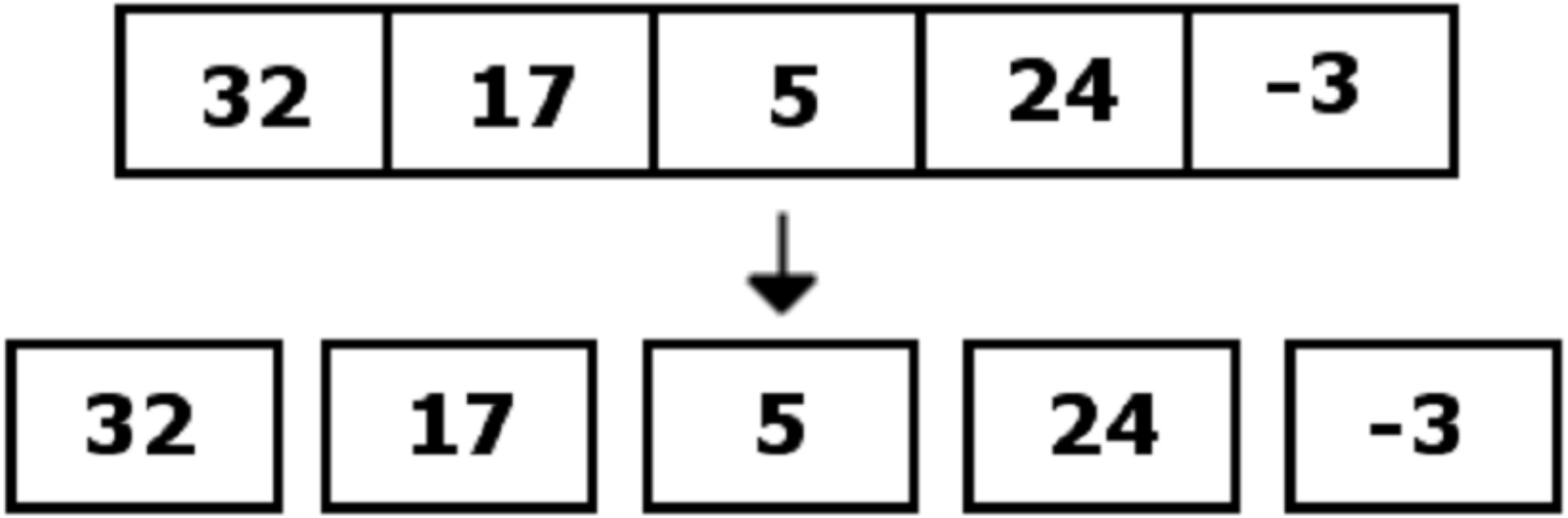
- An `add` or `remove` operation on an `ArrayList` that is not at the end of the list will require elements to be shifted.
  - This can be slow for a large list.
  - What is the worst possible case?





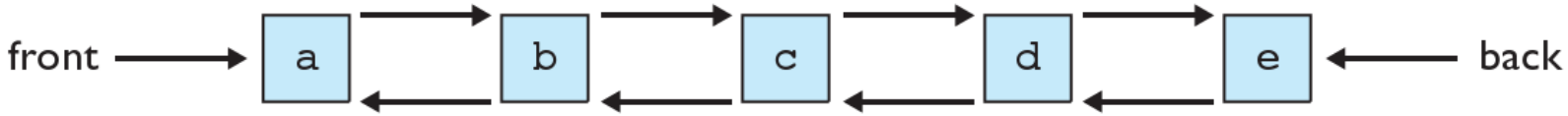
The underlying issue

- the elements of an `ArrayList` are too tightly attached; can't easily rearrange them
- can we break the element storage apart into a more dynamic and flexible structure?



Linked list

- **linked list**: a list implemented using a linked sequence of values
  - each value is stored in a small object called a **node**, which also contains references to its neighbor nodes
  - the list keeps a reference to the first and/or last node
  - in Java, represented by the class `LinkedList`



LinkedList usage example

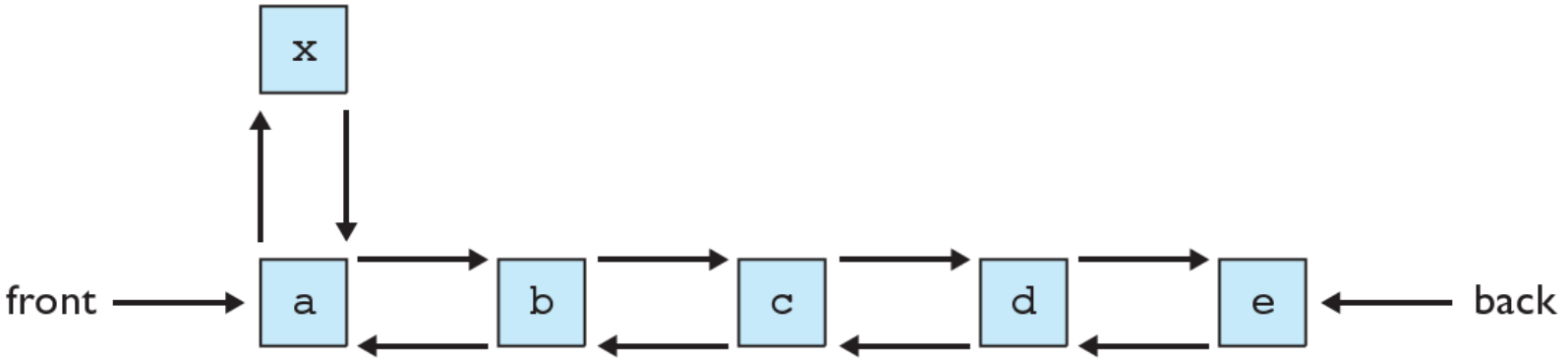
- A `LinkedList` can be used much like an `ArrayList`:

```
LinkedList <String> words = new LinkedList<String>();
words.add("hello");
words.add("goodbye");
words.add("this");
words.add("that");
```

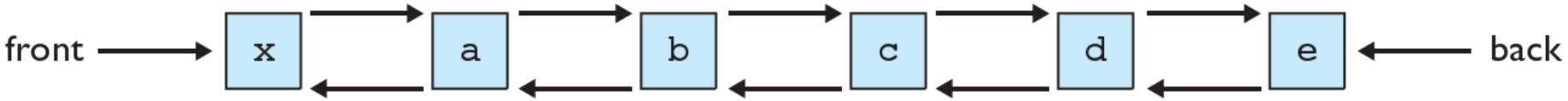
Adding elements to the list

1. Make a new node to hold the new element.

2. Connect the new node to the other nodes in the list.

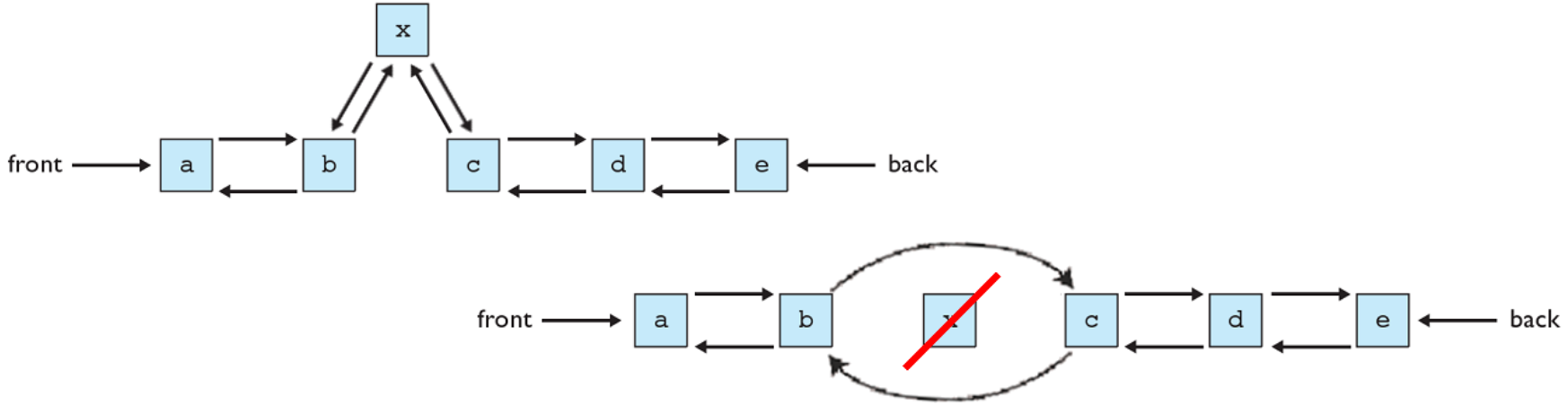


3. Change the front of the list to point to the new node.



Linked list performance

- To add, remove, get a value at a given index:
  - The list must advance through the list to the node just before the one with the proper index.
  - Example: To add a new value to the list, the list creates a new node, walks along its existing node links to the proper index, and attaches it to the nodes that should precede and follow it.
  - This is very fast when adding to the front or back of the list (because the list contains references to these places), but slow elsewhere.



Iterators

A particularly slow idiom

```
List<String> list = new LinkedList<String>();
// ... (put a lot of data into the list)

// print every element of linked list
for (int i = 0; i < list.size(); i++) {
    Object element = list.get(i);
    System.out.println(i + ": " + element);
}
```

- This code executes a slow operation (`get`) every pass through a loop that runs many times
  - this code will take prohibitively long to run for large data sizes

The problem of position

- The code on the previous slide is wasteful because it throws away the position each time.
  - Every call to `get` has to re-traverse the list.

- It would be much better if we could somehow keep the list in place at each index as we looped through it.

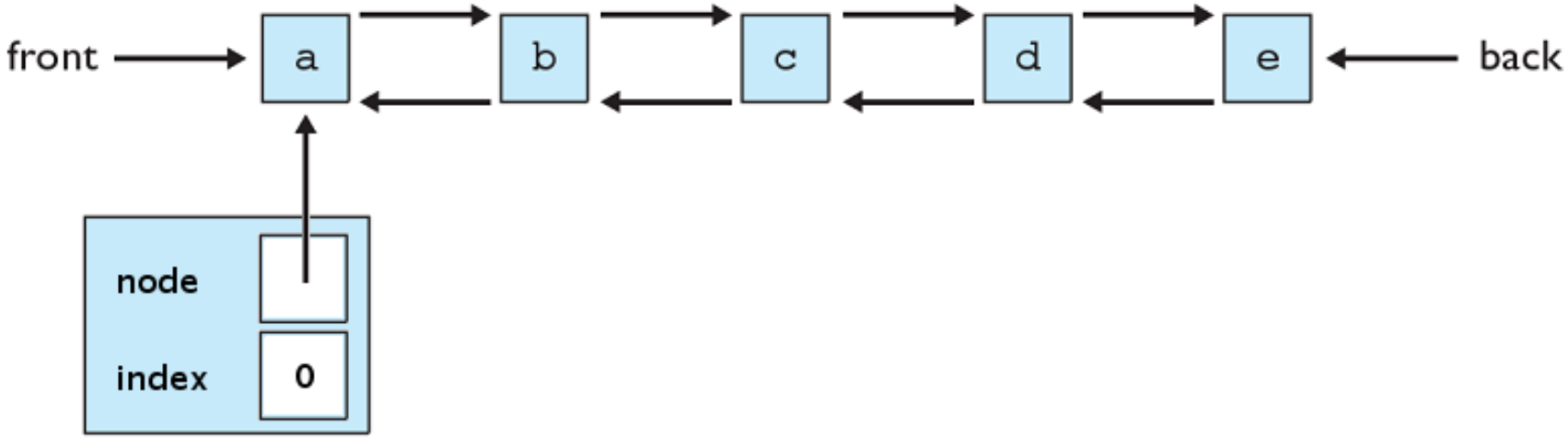
- Java uses special objects to represent a position of a collection as it's being examined
  - These objects are called **iterators**.

Iterators in Java

- interface `Iterator<E>`
  - `public boolean hasNext()`
    Returns `true` if there are more elements to see
  - `public E next()`
    Returns the next object
    in this collection, then
    advances the iterator;
    throws an exception
    if no more elements
    remain
  - `public void remove()`
    Deletes the element that was
    last returned by `next` (not always supported)

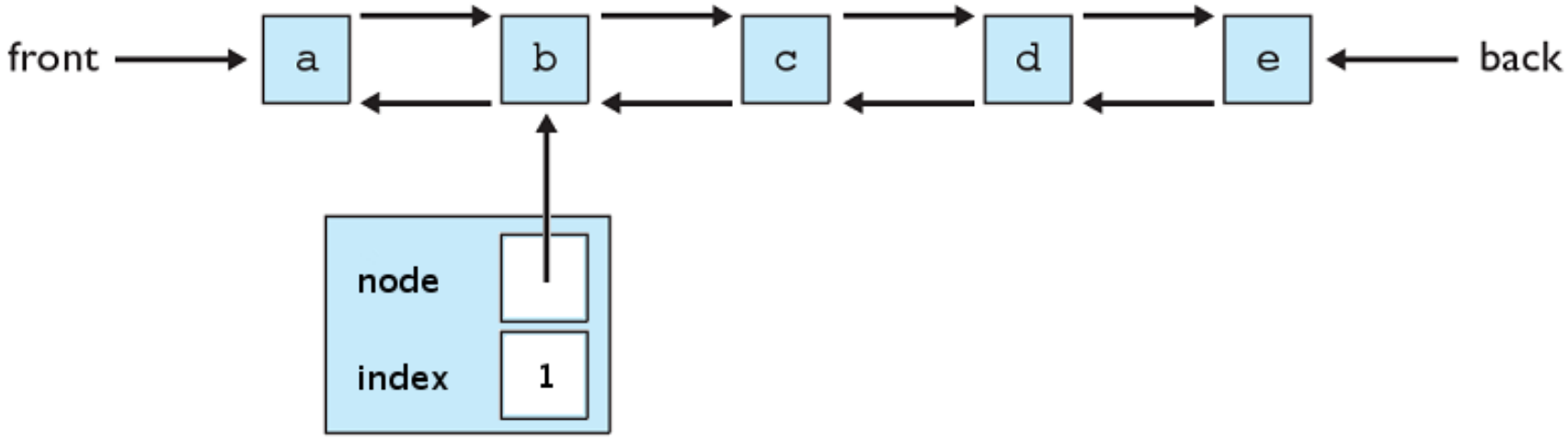
Iterators on linked lists

- an iterator on a linked list maintains (at least) its current index and a reference to that node
- when `iterator()` is called on a linked list, the iterator initially refers to the first node (index 0)



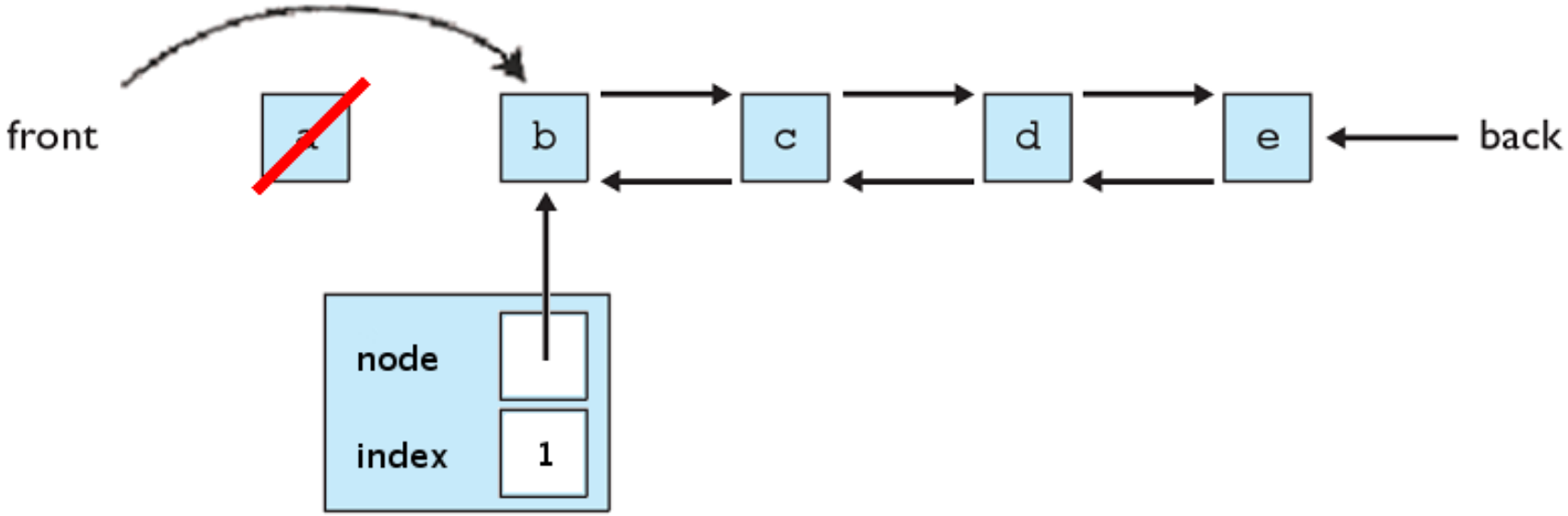
Linked list iterator iteration

- When `next()` is called, the iterator:
  - grabs its current node's element value (`"a"`)
  - follows the `next` reference on its node and increments its index
  - returns the element it grabbed (`"a"`)
- `hasNext` is determined by whether the iterator has reached the back of the list



Iterator's `remove`

- The `remove` removes the last value that was returned by a call to `next`
  - in other words, it deletes the element just *before* the iterator's current node



Fixing the slow LL idiom

```
// print every element of the list
for (int i = 0; i < list.size(); i++) {
    Object element = list.get(i);
    System.out.println(i + ": " + element);
}
```

```
Iterator<Integer> itr = list.iterator();
for (int i = 0; itr.hasNext(); i++) {
    Object element = itr.next();
    System.out.println(i + ": " + element);
}
```

Iterator usage idiom

- The standard idiom of using an iterator:

```
Iterator<E> itr = <collection>.iterator();
while (itr.hasNext()) {
    <do something with itr.next() >;
}
```

- The following code efficiently removes all Strings with an even number of characters from a linked list:

```
// removes all strings of even length from the list
public static void removeEvenLength(LinkedList<String> list) {
    Iterator<String> i = list.iterator();
    while (i.hasNext()) {
        String element = i.next();
        if (element.length() % 2 == 0) {
            i.remove();
        }
    }
}
```

Benefits of iterators

- speed up loops over linked lists' elements

- a unified way to examine all elements of a collection
  - every collection in Java has an `iterator` method
    - in fact, that's the *only* guaranteed way to examine the elements of any `Collection`
  - don't need to look up different collections' method names to see how to examine their elements

- don't have to use indexes as much on lists

Iterator is still not perfect

```
// print odd-valued elements, with their indexes
Iterator<Integer> itr = list.iterator();
for (int i = 0; itr.hasNext(); i++) {
    int element = itr.next();
    if (element % 2 == 1) {
        System.out.println(i + ": " + element);
    }
    i++;
}
```

- We still had to maintain the index variable `i` so that we could print the index of each element.
- We can't use the iterator to add or set elements.
  - The iterator is programmed to crash if the list is modified externally while the iterator is examining it.

More iterator problems

```
// add a 0 after any odd element
Iterator<Integer> itr = list.iterator();
int i = 0;
while (itr.hasNext()) {
    int element = itr.next();
    if (element % 2 == 1) {
        list.add(i, new Integer(0));    // fails
    }
}
```

- the iterator speeds up `get` and `remove` loops only
- the iterator really should be able to help us speed up loops that `add` elements or `set` elements' values!

Concurrent modification

```
public void doubleList(LinkedList<Integer> list) {
    Iterator<Integer> i = list.iterator();
    while (i.hasNext()) {
        int next = i.next();
        list.add(next);       // ConcurrentModificationException
    }
}
```

- While you are still iterating, you cannot call any methods on the list that modify the list's contents.
  - The above code crashes with a `ConcurrentModificationException`.
  - It is okay to call a method on the *iterator itself* that modifies the list (`remove`)

List abstract data type (ADT)

- **abstract data type (ADT)**: a general specification for a type of data structure
  - specifies what data the data structure can hold
  - specifies what operations can be performed on that data
  - does NOT specify exactly how the data structure holds the data internally, nor how it implements each operation

- Example ADT: **List**
  - list ADT specifies that a list collection will store elements in order with integer indexes (allowing duplicates and null values)
  - list ADT specifies that a list collection supports add, remove, get(index), set(index), size, isEmpty, ...
  - `ArrayList` and `LinkedList` both implement the data/operations specified by the list ADT

- ADTs in Java are specified by interfaces
  - `ArrayList` and `LinkedList` both implement `List` interface

ADT usage example

- The following method can accept either an `ArrayList` or a `LinkedList` as its parameter:

```
// returns the longest string in the given list
// pre: list.size() > 0
public static String longest(List<String> list) {
    Iterator<String> i = list.iterator();
    String result = i.next();
    while (i.hasNext()) {
        String next = i.next();
        if (next.length() > result.length()) {
            result = next;
        }
    }
    return result;
}
```

`Collections` class

- The following static methods in the `Collections` class operate on either type of list.
  - Example:

```
Collections.replaceAll(list, "hello", "goodbye");
```

Method name	Description
`binarySearch(`*list*`, `*value*`)`	searches a sorted list for a value and returns its index
`copy(`*dest*`, `*source*`)`	copies all elements from one list to another
`fill(`*list*`, `*value*`)`	replaces all values in the list with the given value
`max(`*list*`)`	returns largest value in the list
`min(`*list*`)`	returns smallest value in the list
`replaceAll(`*list*`, `*oldValue*`, `*newValue*`)`	replaces all occurrences of *oldValue* with *newValue*
`reverse(`*list*`)`	reverses the order of elements in the list
`rotate(`*list*`, `*distance*`)`	shifts every element's index by the given distance
`sort(`*list*`)`	places the list's elements into natural sorted order
`swap(`*list*`, `*index1*`, `*index2*`)`	switches element values at the given two indexes

Sets

reading: 10.2

Application: words in a book

- Write an application that reads in the text of a book (say, *Moby Dick*) and then lets the user type words, and tells whether those words are contained in *Moby Dick* or not.
  - How would we implement this with a List?
  - Would this be a good or bad implementation?
- Notice that the code to solve this problem doesn't use much of the list functionality (only add and search)
  - Does the ordering of the elements in the List affect the algorithm? Could we use this information to our advantage?

A new ADT: Set

- **set**: an unordered collection with no duplicates
  - The main purpose of a set is to search it, to test objects for membership in the set (`contains`).
  - Java has an interface named `Set<E>` to represent this kind of collection.
    - `Set` is an interface; you can't say `new Set()`
  - There are two `Set` implementations in Java: `TreeSet` and `HashSet`
    - Java's set implementations have been optimized so that it is very fast to search for elements in them.

Java Set interface

- Interface `Set` has exactly the methods of the `Collection` interface
- `TreeSet` and `HashSet` classes implement the `Set` interface.

```
Set<Integer> set = new TreeSet<Integer>();
```

- Notice: These list methods are missing from `Set`:
  - `get(`*index*`)`
  - `add(`*index*`, `*value*`)`
  - `remove(`*index*`)`

- To access each element of a set, use its `iterator` method instead.

Set usage example

- The following code illustrates the usage of a set:

```
Set<String> stooges = new HashSet<String>();
stooges.add("Larry");
stooges.add("Moe");
stooges.add("Curly");
stooges.add("Moe");    // duplicate, won't be added
stooges.add("Shemp");
stooges.add("Moe");    // duplicate, won't be added
System.out.println(stooges);
```

- Output:

```
[Moe, Shemp, Larry, Curly]
```

  - Notice that the order of the stooges doesn't match the order in which they were added, nor is it the natural alphabetical order.

TreeSet vs. HashSet

- The preceding code can use `TreeSet` instead:

```
Set<String> stooges = new TreeSet<String>();
...
System.out.println(stooges);
```

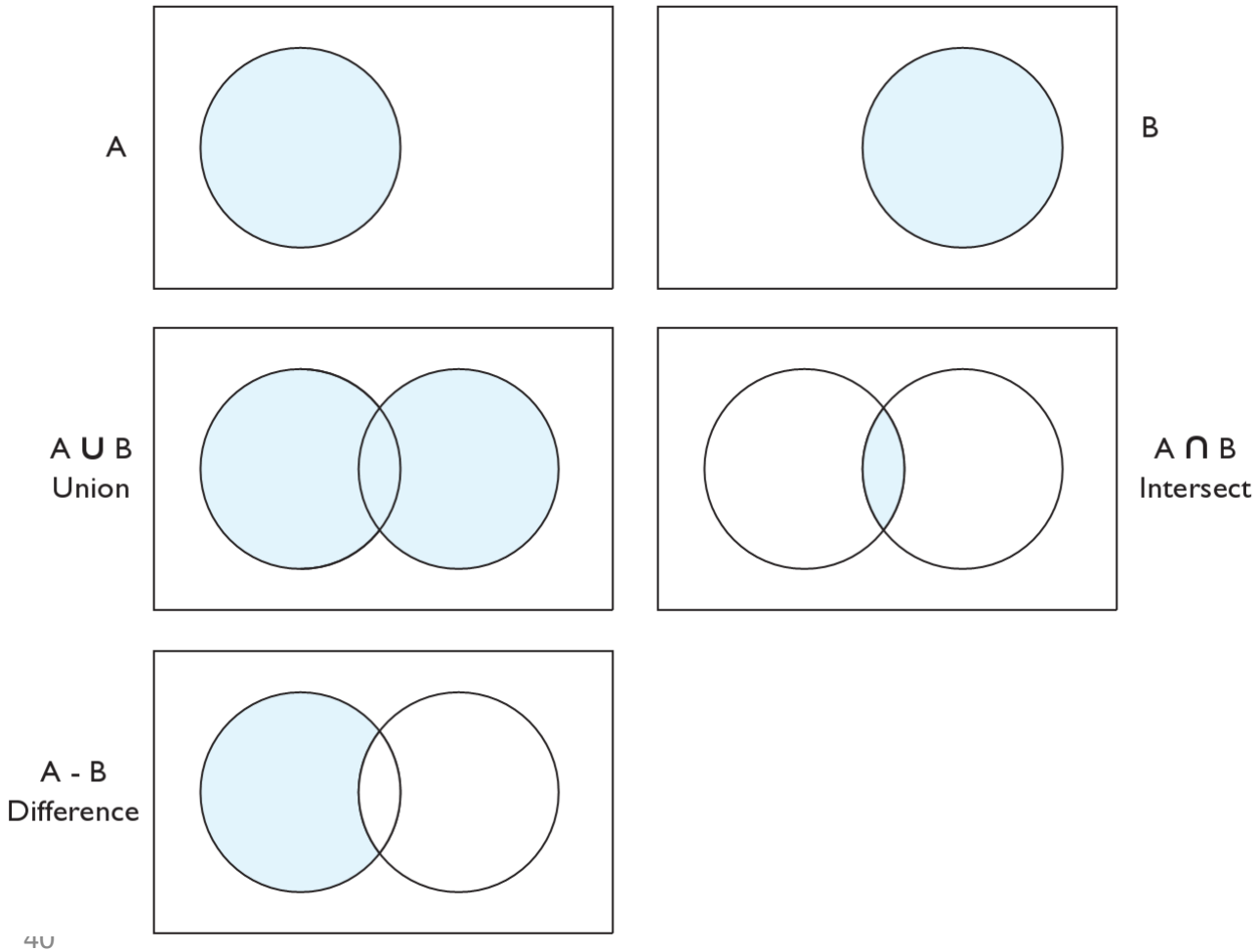
- Output:

```
[Curly, Larry, Moe, Shemp]
```

- `TreeSet` vs. `HashSet`:
  - A `TreeSet` stores its elements in the natural alphabetical order.
  - `TreeSet` can only be used with elements with an ordering (it can't easily store `Point` objects, for example).
  - `TreeSet` is slightly (often not noticeably) slower than `HashSet`.

Set operations

- Sets support common operations to combine them with, or compare them against, other sets:



Typical set operations

- sometimes it is useful to compare sets:
  - **subset**: S1 is a *subset* of S2 if S2 contains every element from S1.
    - `containsAll` tests for a subset relationship.

- it can be useful to combine sets in the following ways:
  - **union**: S1 *union* S2 contains all elements that are in S1 or S2.
    - `addAll` performs set union.
  - **intersection**: S1 *intersect* S2 contains only the elements that are in *both* S1 and S2.
    - `retainAll` performs set intersection.
  - **difference**: S1 *difference* S2 contains the elements that are in S1 that are *not* in S2.
    - `removeAll` performs set difference.

Maps

reading: 10.3

A variation: book word count

- Previously, we discussed an application that reads in the text of a book (say, *Moby Dick*) and then lets the user type words, and tells whether those words are contained in *Moby Dick* or not.

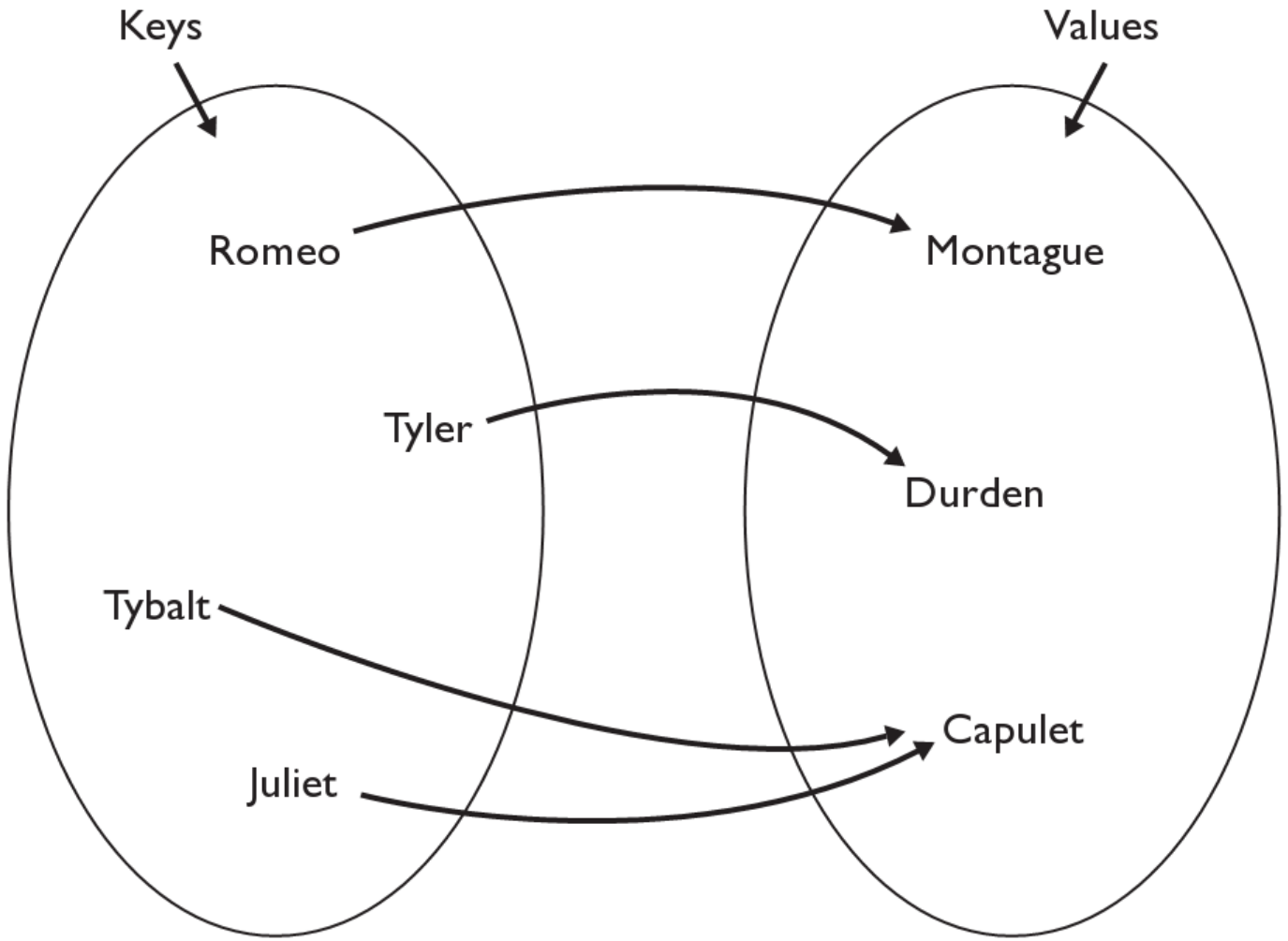
- What if we wanted to change this program to not only tell us whether the word exists in the book, but also *how many times* it occurs?

Mapping between sets

- sometimes we want to create a mapping between elements of one set and another set
  - example: map words to their count in the book
    - "the" --> 325
    - "whale" --> 14
  - example: map people to their phone numbers
    - "Marty Stepp" --> "692-4540"
    - "Jenny" --> "867-5309"
- How would we do this with a list (or list(s))?
  - A list doesn't map people to phone numbers; it maps `int`s from 0 .. *size* - 1 to objects
  - Could we map some `int` to a person's name, and the same `int` to the person's phone number?
  - How would we find a phone number, given the person's name? Is this a good solution?

Map diagram

- A map associates each key with a value.



A new ADT: Map

- **map**: an unordered collection that associates a collection of element values with a set of keys so that elements they can be found very quickly
  - Each key can appear at most once (no duplicate keys)
  - A key maps to at most one value
  - the main operations:
    - **put**(key, value)
      "Map this *key* to that *value*."
    - **get**(key)
      "What value, if any, does this key map to?"
  - Maps are represented in Java by the `Map<K, V>` interface.
    - Two implementations: `HashMap` and `TreeMap`

Map methods

- Maps don't implement the `Collection` interface, but they do have the following public methods:

Method name	Description
`clear()`	removes all keys and values from the map
`containsKey(`*key*`)`	returns `true` if the given key exists in the map
`containsValue(`*value*`)`	returns `true` if the given value exists in the map
`get(`*key*`)`	returns the value associated with the given key (`null` if not found)
`isEmpty()`	returns `true` if the map has no keys or values
`keySet()`	returns a collection of all keys in the map
`put(`*key*`, `*value*`)`	associates the given key with the given value
`putAll(`*map*`)`	adds all key/value mappings from given map
`remove(`*key*`)`	removes the given key and its associated value
`size()`	returns the number of key/value pairs in the map
`values()`	returns a collection of all values in the map

Basic Map usage

- Maps are declared with two type parameters, one for the keys and one for the values:

```
Map<String, Double> salaryMap = new HashMap<String, Double>();
salaryMap.put("Stuart", 20000.00);
salaryMap.put("Marty", 15500.00);
salaryMap.put("Jenny", 86753.09);
System.out.println(salaryMap);

// search the map for a name
if (salaryMap.containsKey("Jenny")) {
    double salary = salaryMap.get("Jenny");
    System.out.println("Jenny's salary is $" + salary);
} else {
    System.out.println("I don't have a record for Jenny");
}
```

- Output:

```
{Jenny=86753.09, Stuart=20000.0, Marty=15500.0}
Jenny's salary is $86753.09
```

TreeMap vs. HashMap

- Remember that Map is an interface.
  - You can't say `Map m = new Map();`

- Java has two classes that implement the Map interface:
  - `TreeMap`
    - elements are stored in their natural Comparable order
    - slightly slower
    - can only be used on elements with an ordering
  - `HashMap`
    - elements are stored in an unpredictable order
    - faster to add, search, remove

Collection views

- A map itself is not regarded as a collection.
  - `Map` does not implement `Collection` interface
  - although, in theory, it could be seen as a collection of pairs

- Instead collection *views* of a map may be obtained:
  - a Set of its keys
  - a Collection of its values (not a set... why?)

Iterators and `Maps`

- `Map` has no `iterator` method; you can't get an `Iterator` directly

- You must first call either:
  - `keySet()` returns a `Set` of all the keys in this `Map`
  - `values()` returns a `Collection` of all the values in this `Map`

- Then call `iterator()` on the key set or value collection.
  - Examples:

```
Iterator<String> keyItr = grades.keySet().iterator();
Iterator<String> elementItr = grades.values().iterator();
```

  - You can also use the enhanced for loop over these collections:

```
for (int ssn : ssnMap.values()) {
    System.out.println("Social security #: " + ssn);
}
```

Map example

```
import java.util.*;

public class Birthday {
    public static void main(String[] args){
        Map<String, Integer> m = new HashMap<String, Integer>();
        m.put("Newton", 1642);
        m.put("Darwin", 1809);
        System.out.println(m);

        Set<String> keys = m.keySet();
        Iterator<String> itr = keys.iterator();
        while (itr.hasNext()) {
            String key = itr.next();
            System.out.println(key + " => " + m.get(key));
        }
    }
}
```

- Output:

```
{Darwin=1809, Newton=1642}
Darwin => 1809
Newton => 1642
```

`Map` practice problems

- Write code to invert a `Map`; that is, to make the values the keys and make the keys the values.

```
Map<String, String> byName =
    new HashMap<String, String>();
byName.put("Darwin", "748-2797");
byName.put("Newton", "748-9901");

Map<String, String> byPhone = new HashMap<String, String>();
// ... your code here!
System.out.println(byPhone);
```

Output:

{748-2797=Darwin, 748-9901=Newton}

- Write a program to count words in a text file, using a hash map to store the number of occurrences of each word.