Principles of Software Construction: Objects, Design, and Concurrency

Part 2: Design case studies

Design case study: Java Collections

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Administrivia

- Homework 4b due next Thursday, October 17th
- Homework 4a feedback available
  - Can regain up to 75% of lost Homework 4a credit
    - Directly address TA comments when you turn in Homework 4c
    - Turn in revised design documents + scans of our feedback + description of what you changed

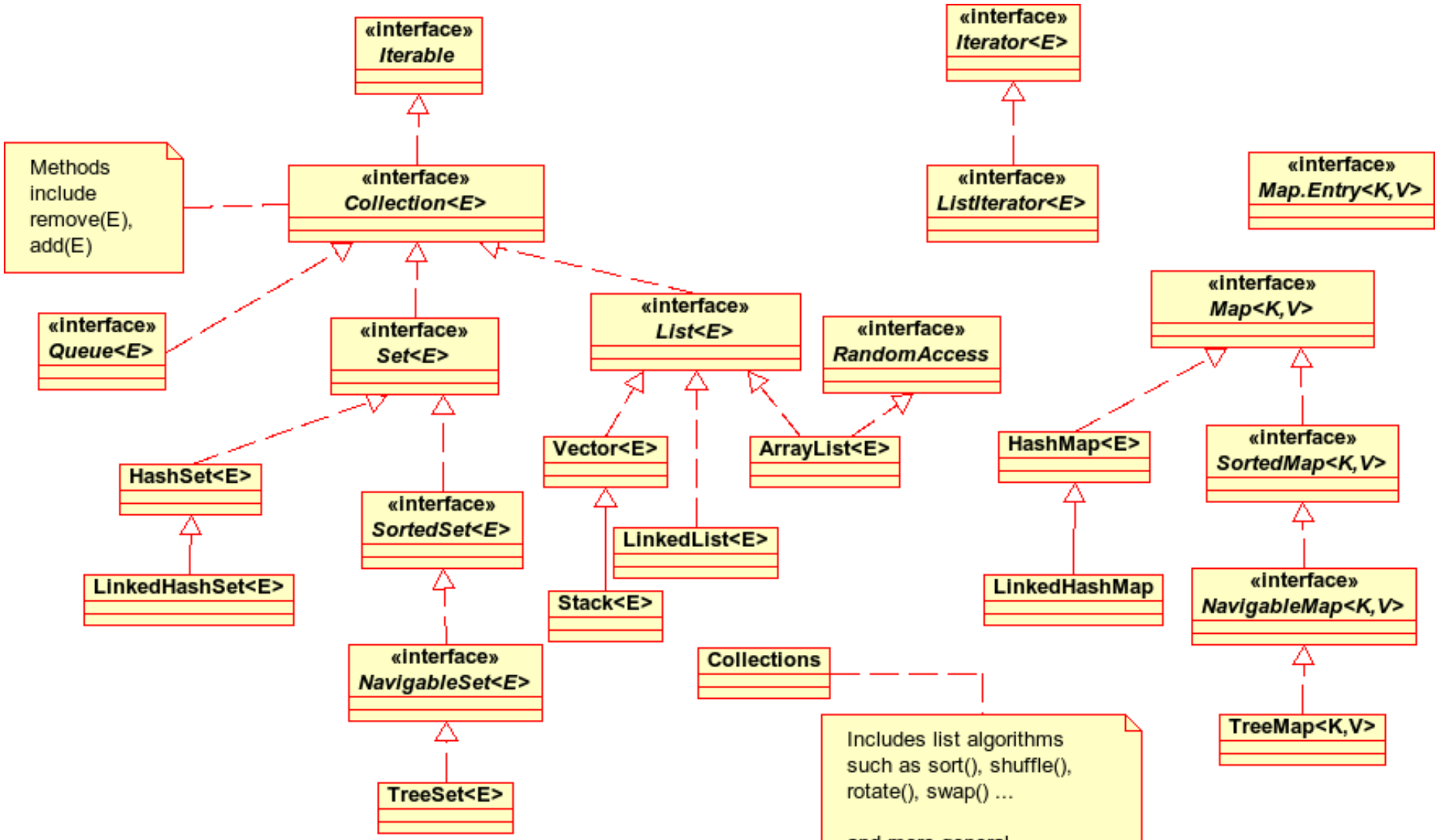
https://commons.wikimedia.org/wiki/File:1_carcassonne_aerial_2016.jpg

Key concepts from Tuesday

Key concepts from Tuesday

- GUIs are filled with design patterns
  - Strategy
  - Template method
  - Observer
  - Composite
  - Decorator
  - Adapter
  - Façade
  - Command
  - Chain of responsibility

Today: Java Collections



Source: http://wiki3.cosc.canterbury.ac.nz/index.php/User:Jenny_Harlow/Design_study/Java_Collections_Framework

Learning goals for today

- Understand the design challenges of collection libraries.
- Recognize the design patterns used and how those design patterns achieve design goals.
  - Marker interface
  - Decorator
  - Factory method
  - Iterator
  - Strategy
  - Template method
  - Adapter

Designing a data structure library

- Different data types: lists, sets, maps, stacks, queues, …
- Different representations
  - Array-based lists vs. linked lists
  - Hash-based sets vs. tree-based sets
  - …
- Many alternative design decisions
  - Mutable vs. immutable
  - Sorted vs. unsorted
  - Primitive data vs. objects
  - Accepts null or not
  - Accepts duplicates or not
  - Concurrency/thread-safe or not
  - …

The philosophy of the Collections framework

- Powerful and general
- Small in size and conceptual weight
  - Must feel familiar
  - Only include fundamental operations
  - "Fun and easy to learn and use"

Overview of the Collections framework

- Core interfaces
- General-purpose implementations
- Wrapper and special-purpose implementations
- Abstract implementations for easy reuse
- Separate algorithms library

Example: How to find anagrams

- Alphabetize the characters in each word
  - cat → act, dog → dgo, mouse → emosu
  - Resulting string is called *alphagram*
- Anagrams share the same alphagram!
  - stop → opst, post → opst, tops → opst, opts → opst
- So go through word list making "multimap" from alphagram to word!

How to find anagrams in Java (1)

```
public static void main(String[] args) throws IOException {
    // Read words from file and put into a simulated multimap
    Map<String, List<String>> groups = new HashMap<>();
    try (Scanner s = new Scanner(new File(args[0]))) {
        while (s.hasNext()) {
            String word = s.next();
            String alpha = alphabetize(word);
            List<String> group = groups.get(alpha);
            if (group == null)
                groups.put(alpha, group = new ArrayList<>());
            group.add(word);
        }
    }
```

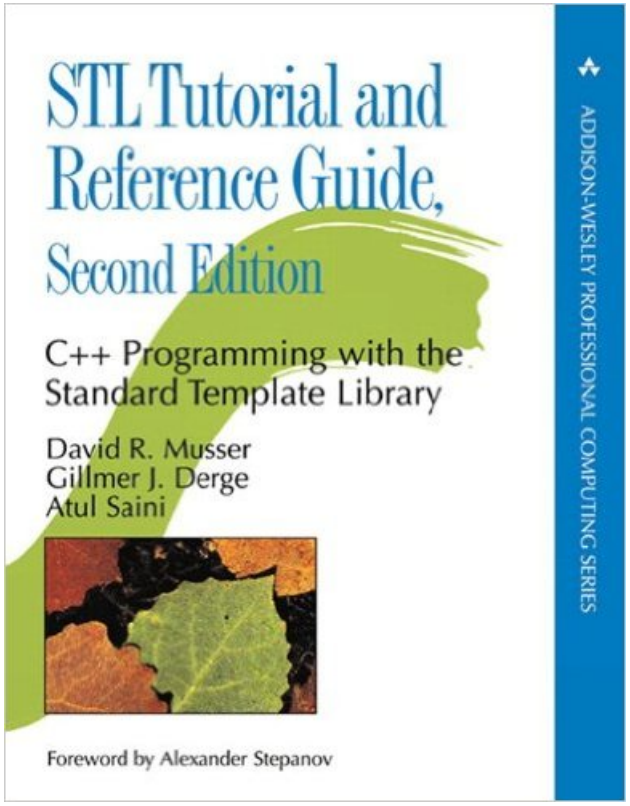
How to find anagrams in Java (2)

```
    // Print all anagram groups above size threshold
    int minGroupSize = Integer.parseInt(args[1]);
    for (List<String> group : groups.values())
        if (group.size() >= minGroupSize)
            System.out.println(group.size() + ": " + group);
}

// Returns the alphagram for a string
private static String alphabetize(String s) {
    char[] a = s.toCharArray();
    Arrays.sort(a);
    return new String(a);
}
```

Two slides in Java vs. **a chapter** in STL

Java's verbosity is somewhat exaggerated



The `Collection` interface

```
public interface Collection<E> {
    int size();
    boolean isEmpty();
    boolean contains(Object element);
    boolean add(E element);          // Optional
    boolean remove(Object element); // Optional
    Iterator<E> iterator();

    Object[] toArray();
    T[] toArray(T a[]);

    // Bulk operations
    boolean containsAll(Collection<?> c);
    boolean addAll(Collection<? extends E> c); // Optional
    boolean removeAll(Collection<?> c);  // Optional
    boolean retainAll(Collection<?> c);  // Optional
    void clear();                        // Optional
    …
}
```

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The `List` interface: an ordered collection

```
public interface List<E> extends Collection<E> {
    E get(int index);
    E set(int index, E element);     // Optional
    void add(int index, E element);  // Optional
    Object remove(int index);        // Optional
    boolean addAll(int index, Collection<? extends E> c);
                                     // Optional
    int indexOf(Object o);
    int lastIndexOf(Object o);

    List<E> subList(int from, int to);

    ListIterator<E> listIterator();
    ListIterator<E> listIterator(int index);
}
```

The Set interface: collection of distinct items

```
public interface Set<E> extends Collection<E> {
}
```

- Adds no methods!
- Specification requires no duplicate items in collection
- The *marker interface* design pattern
  - Marker interfaces add invariants, no code

The Map interface: key-value mapping

```
public interface Map<K,V> {
    int size();
    boolean isEmpty();
    boolean containsKey(Object key);
    boolean containsValue(Object value);
    Object get(Object key);
    Object put(K key, V value);   // Optional
    Object remove(Object key);    // Optional
    void putAll(Map<? extends K, ? extends V> t); // Opt.
    void clear();                 // Optional

    // Collection views
    public Set<K> keySet();
    public Collection<V> values();
    public Set<Map.Entry<K,V>> entrySet();
}
```

Recall the `Iterator` interface

```
public interface Iterator<E> {
    boolean hasNext();
    E next();
    void remove();    // Optional
}
```

Aside: The *factory method* pattern

```
public interface Collection<E> {
    int size();
    boolean isEmpty();
    boolean contains(Object element);
    boolean add(E element);          // Optional
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    boolean containsAll(Collection<?> c);
    boolean addAll(Collection<? extends E> c); // Optional
    boolean removeAll(Collection<?> c);  // Optional
    boolean retainAll(Collection<?> c);  // Optional
    void clear();                        // Optional

    …
}
```

Defines an interface for creating an iterator, but allows collection implementation to decide which iterator to create.

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The factory method design pattern

- Problem: Subclasses need to control the type of object created
- Solution: Define an method that constructs the object; subclasses can override the method.
- Consequences:
  - Names can be meaningful, self-documenting
  - Can avoid constructing a new object
  - Might be hard to distinguish factory method from other methods

Other factory method examples

- From `java.util.Collections`:

```
List<T>  emptyList();
Set<T>   emptySet();
Map<K,V> emptyMap();
Set<T>   singleton(T item);
List<T>  singletonList(T item);
List<T>  nCopies(int n, T item);
```

General-purpose implementations

Interface	Implementation
`Set`	`HashSet`
`List`	`ArrayList`
`Queue`	`ArrayDeque`
`Deque`	`ArrayDeque`
`[stack]`	`ArrayDeque`
`Map`	`HashMap`

General-purpose implementations (continued)

Interface	Implementation(s)
`List`	`LinkedList`

`Set`	`LinkedHashSet`
	`TreeSet`
	`EnumSet`

`Queue`	`PriorityQueue`

`Map`	`LinkedHashMap`
	`TreeMap`
	`EnumMap`

Wrapper and special-purpose implementations

- Unmodifiable collections (from `java.util.Collections`):

```
Collection<T> unmodifiableCollection(Collection<? extends T> c);
List<T> unmodifiableList(List<? extends T> list);
Map<K,V> unmodifiableMap(Map<? extends K, ? extends V> m);
```

Wrapper and special-purpose implementations

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Collection<T> unmodifiableCollection(Collection<? extends T> c);
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```

- Synchronized collections (from `java.util.Collections`):

```
Collection<T> synchronizedCollection(Collection<? extends T> c);
List<T> synchronizedList(List<? extends T> list);
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Wrapper and special-purpose implementations

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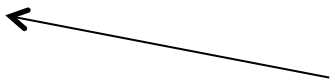
Collection<T> synchronizedCollection(Collection<? extends T> c);
List<T> synchronizedList(List<? extends T> list);
Map<K,V> synchronizedMap(Map<? extends K, ? extends V> m);
```

- A `List` backed from an array (from `java.util.Arrays`):

```
List<T> asList(T… a);
```



The adapter pattern: Returns a specialized list implementation that adapts the array API to the `java.util.List` API

e.g., The UnmodifiableCollection class

```
public static <T> Collection<T> unmodifiableCollection(Collection<T> c)
  return new UnmodifiableCollection<>(c);
}

class UnmodifiableCollection<E>
                implements Collection<E>, Serializable {

  final Collection<E> c;

  UnmodifiableCollection(Collection<> c) {this.c = c; }
  public int       size()              {return c.size();}
  public boolean   isEmpty()           {return c.isEmpty();}
  public boolean   contains(Object o)  {return c.contains(o);}
  public Object[] toArray()            {return c.toArray();}
  public <T> T[]   toArray(T[] a)      {return c.toArray(a);}
  public String    toString()          {return c.toString();}
  public boolean   add(E e) {throw new UnsupportedOperationException(); }
  public boolean   remove(Object o)    { throw new UnsupportedOperationEx
  public boolean   containsAll(Collection<?> coll) { return c.containsAll
  public boolean   addAll(Collection<? extends E> coll) { throw new Unsup
  public boolean   removeAll(Collection<?> coll) { throw new UnsupportedO
```

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public static <T> Collection<T> u                    llection<T> c)
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  final Collection<E> c;

  UnmodifiableCollection(Collection<> c) {this.c = c; }
  public int      size()              {return c.size();}
  public boolean  isEmpty()           {return c.isEmpty();}
  public boolean  contains(Object o)  {return c.contains(o);}
  public Object[] toArray()           {return c.toArray();}
  public <T> T[]  toArray(T[] a)      {return c.toArray(a);}
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  public boolean  add(E e) {throw new UnsupportedOperationException(); }
  public boolean  remove(Object o)    { throw new UnsupportedOperationEx
  public boolean  containsAll(Collection<?> coll) { return c.containsAll
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What design pattern is this?

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  final Collection<E> c;

  UnmodifiableCollection(Collection<> c) {this.c = c; }
  public int      size()              {return c.size();}
  public boolean  isEmpty()           {return c.isEmpty();}
  public boolean  contains(Object o)  {return c.contains(o);}
  public Object[] toArray()           {return c.toArray();}
  public <T> T[]  toArray(T[] a)      {return c.toArray(a);}
  public String   toString()          {return c.toString();}
  public boolean  add(E e) {throw new UnsupportedOperationException(); }
  public boolean  remove(Object o)    { throw new UnsupportedOperationEx
  public boolean  containsAll(Collection<?> coll) { return c.containsAll
  public boolean  addAll(Collection<? extends E> coll) { throw new Unsup
  public boolean  removeAll(Collection<?> coll) { throw new UnsupportedO
```

What design pattern is this?

UnmodifiableCollection decorates Collection by removing functionality…

Abstract implementations for easy reuse

```
public abstract AbstractList<E> extends AbstractCollection<E>
                                                    implements List<E> {
    abstract public int size();
    abstract public E get(int index);

    public boolean isEmpty() { return size() == 0; }
    public boolean contains(Object element) {
        for (int i = 0; i < size(); i++) {
            if (get(i).equals(element)) {
                return true;
            }
        }
        return false;
    }
    public boolean add(int index, E element) { throw new UnsupportedOp
    public boolean remove(int index) { throw new UnsupportedOperationE
    …
}
```

Implementing a new list type

```
/**
 * Returns an unmodifiable view of the given list, equivalent to
 * the reverse of the given list.  The return value is backed
 * by the original list, using O(1) additional space.
 */
public static <T> List<T> reverseOf(List<T> list) { ... }
```

Implementing a new list type

```
/**
 * Returns an unmodifiable view of the given list, equivalent to
 * the reverse of the given list.  The return value is backed
 * by the original list, using O(1) additional space.
 */
public static <T> List<T> reverseOf(List<T> list) {
    return new AbstractList<T>() {
        @Override
         public int size() {
            return list.size();
         }

         @Override
         public T get(int index) {
            return list.get(size() - index - 1)
         }
    };
}
```

Abstract implementations for easy reuse

```
public abstract AbstractList<E> extends AbstractCollection<E>
                                                implements List<E> {
    abstract public int size();
    abstract public E get(int index);

    public boolean isEmpty() { return size() == 0; }
    public boolean contains(Object element) { … }
    public boolean add(int index, E element) { throw new UnsupportedOp
    public boolean remove(int index) { throw new UnsupportedOperationE
    …
}
```

What design pattern is this?

Abstract implementations for easy reuse

```
public abstract AbstractList<E> extends AbstractCollection<E>
                                                implements List<E> {
    abstract public int size();
    abstract public E get(int index);

    public boolean isEmpty() { return size() == 0; }
    public boolean contains(Object element) { … }
    public boolean add(int index, E element) { throw new UnsupportedOp
    public boolean remove(int index) { throw new UnsupportedOperationE
    …
}
```

What design pattern is this?

The template method design pattern: `size` and `get` are primitive operations, other methods are template methods.

Reusable algorithms in `java.util.Collections`

```
static <T extends Comparable<? super T>> void sort(List<T> list);
static int binarySearch(List list, Object key);
static <T extends Comparable<? super T>> T min(Collection<T> coll);
static <T extends Comparable<? super T>> T max(Collection<T> coll);
static <E> void fill(List<E> list, E e);
static <E> void copy(List<E> dest, List<? Extends E> src);
static void reverse(List<?> list);
static void shuffle(List<?> list);
```

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e.g. sorting a Collection

- Using `Collections.sort`:

```
public static void main(String[] args) {
  List<String> list = Arrays.asList(args);
  Collections.sort(list);
  for (String s : list) {
    System.out.println(s);
  }
}
```

Sorting your own types of objects

```
public interface Comparable<T> {
  int compareTo(T o);
}
```

- General contracts:
  - `a.compareTo(b)` should return:

< 0	if `a` is less than `b`
0	if `a` and `b` are equal
> 0	if `a` is greater than `b`

  - Should define a total order:
    - If `a.compareTo(b)` < 0 and `b.compareTo(c)` < 0, then `a.compareTo(c)` should be < 0
    - If `a.compareTo(b)` < 0, then `b.compareTo(a)` should be > 0
  - Should usually be consistent with `.equals`:
    - `a.compareTo(b)` == 0 iff `a.equals(b)`

Comparable objects – an example

```
public class Integer implements Comparable<Integer> {
  private final int val;
  public Integer(int val) { this.val = val; }
  …
  public int compareTo(Integer o) {
    if (val < o.val) return -1;
    if (val == o.val) return 0;
    return 1;
  }
}
```

Comparable objects – another example

- Make `Name` comparable:

```
public class Name                                    {
  private final String first, last;
  public Name(String first, String last) {
     if (first == null || last == null)
         throw new NullPointerException();
     this.first = first;  this.last = last;
  }
  …




}
```

- Hint: Strings implement `Comparable<String>`

Comparable objects – another example

- Make `Name` comparable:

```
public class Name implements Comparable<Name> {
  private final String first, last;
  public Name(String first, String last) {
     if (first == null || last == null)
         throw new NullPointerException();
     this.first = first;  this.last = last;
  }
  public int compareTo(Name o) {
    int lastComparison = last.compareTo(o.last);
    if (lastComparison != 0) return lastComparison;
    return first.compareTo(o.first);
  }
}
```

Hint: Strings implement Comparable<String>

Alternative comparisons

```
public class Employee implements Comparable<Employee> {
  protected Name name;
  protected int  salary;
  …
}
```

- What if we want to sort Employees by name, usually, but sometimes sort by salary?

Alternative comparisons

```
public class Employee implements Comparable<Employee> {
  protected Name name;
  protected int  salary;
  …
}
```

- What if we want to sort Employees by name, usually, but sometimes sort by salary?
- Answer: There's a Strategy pattern interface for that:

```
public interface Comparator<T> {
  public int     compare(T o1, T o2);
}
```

Writing a Comparator object

```
public class Employee implements Comparable<Employee> {
  protected Name name;
  protected int  salary;
  public int compareTo(Employee o) {
    return name.compareTo(o.name);
  }
}

public class SalaryComparator implements Comparator<Employee> {
  public int compare (Employee o1, Employee o2) {
    return o1.salary – o2.salary;
  }
}
```

Summary

- Collections as reusable and extensible data structures
  - design for reuse
  - design for change
- Iterators to abstract over internal structure
- Decorator to attach behavior at runtime
- Template methods and factory methods to support customization in subclasses
- Adapters to convert between implementations
- Strategy pattern for sorting