Principles of Software Construction:

The Design of the Java Collections API

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Administrivia

- Homework 4b due next Thursday, 10/22
- US General election, Tuesday, 11/3
  - Early voting in process in most states

We take you back now to the 1997

- It was a simpler time
  - Java had only `Vector`, `Hashtable` & `Enumeration`
  - But it needed more; platform was growing!
- The barbarians were pounding the gates
  - JGL was a transliteration of STL to Java
  - It had 130 (!) classes and interfaces
  - The JGL designers wanted badly to put it in the JDK
- It fell to me to design something better

Here’s the first collections talk ever

- Debuted at JavaOne 1998
- No one knew what a collections framework was
  - Or why they needed one
- Talk aimed to
  - Explain the concept
  - Sell Java programmers on this framework
  - Teach them to use it

The Java^{TM} Platform Collections Framework

Joshua Bloch

Sr. Staff Engineer, Collections Architect

Sun Microsystems, Inc.

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What is a Collection?

- Object that groups elements
- Main Uses
  - Data storage and retrieval
  - Data transmission
- Familiar Examples
  - `java.util.Vector`
  - `java.util.Hashtable`
  - `array`

What is a Collections Framework?

- Unified Architecture
  - **Interfaces** - implementation-independence
  - **Implementations** - reusable data structures
  - **Algorithms** - reusable functionality

- Best-known examples
  - C++ Standard Template Library (STL)
  - Smalltalk collections

Benefits

- Reduces programming effort
- Increases program speed and quality
- Interoperability among unrelated APIs
- Reduces effort to learn new APIs
- Reduces effort to design new APIs
- Fosters software reuse

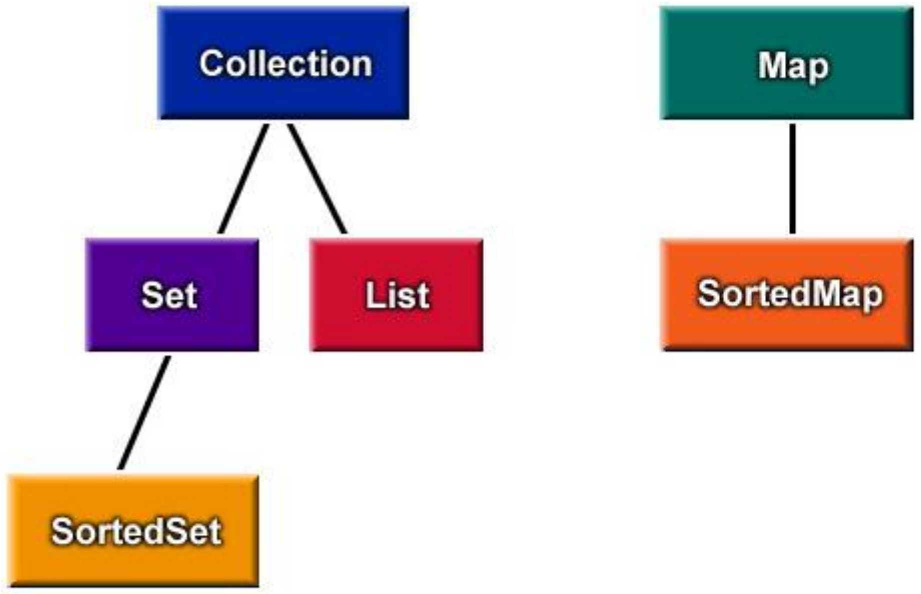
Design Goals

- Small and simple
- Reasonably powerful
- Easily extensible
- Compatible with preexisting collections
- Must feel familiar

Architecture Overview

- Core Collection Interfaces
- General-Purpose Implementations
- Wrapper Implementations
- Abstract Implementations
- Algorithms

Core Collection Interfaces



`Collection` Interface

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

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

    // Bulk Operations
    boolean containsAll(Collection c);
    boolean addAll(Collection c);     // Optional
    boolean removeAll(Collection c);  // Optional
    boolean retainAll(Collection c);  // Optional
    void clear();                     // Optional
}
```

`Iterator` Interface

- Replacement for `Enumeration` interface
  - Adds `remove` method
  - Improves method names

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

Collection Example

Reusable algorithm to eliminate nulls

```
public static boolean removeNulls(Collection c) {
    for (Iterator i = c.iterator(); i.hasNext(); ) {
        if (i.next() == null)
            i.remove();
    }
}
```

Set Interface

- Adds no methods to `Collection`!
- Adds stipulation: no duplicate elements
- Mandates `equals` and `hashCode` calculation

```
public interface Set extends Collection {
}
```

Set Idioms

```
Set s1, s2;

boolean isSubset = s1.containsAll(s2);

Set union = new HashSet(s1);
union.addAll(s2);

Set intersection = new HashSet(s1);
intersection.retainAll(s2);

Set difference = new HashSet(s1);
difference.removeAll(s2);

Collection c;
Collection noDups = new HashSet(c);
```

List Interface

A sequence of objects

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

    List subList(int from, int to);

    ListIterator listIterator();
    ListIterator listIterator(int index);
}
```

List Example

Reusable algorithms to swap and randomize

```
public static void swap(List a, int i, int j) {
    Object tmp = a.get(i);
    a.set(i, a.get(j));
    a.set(j, tmp);
}

private static Random r = new Random(); // Obsolete impl!

public static void shuffle(List a) {
    for (int i = a.size(); i > 1; i--)
        swap(a, i - 1, r.nextInt(i));
}
```

List Idioms

```
List a, b;

// Concatenate two lists
a.addAll(b);

// Range-remove
a.subList(from, to).clear();

// Range-extract
List partView = a.subList(from, to);
List part = new ArrayList(partView);
partView.clear();
```

Map Interface

A key-value mapping

```
public interface Map {
    int size();
    boolean isEmpty();
    boolean containsKey(Object key);
    boolean containsValue(Object value);
    Object get(Object key);
    Object put(Object key, Object value);   // Optional
    Object remove(Object key);              // Optional

    void putAll(Map t);  // Optional
    void clear();        // Optional

    // Collection Views
    public Set keySet();
    public Collection values();
    public Set entrySet();
}
```

Map Idioms

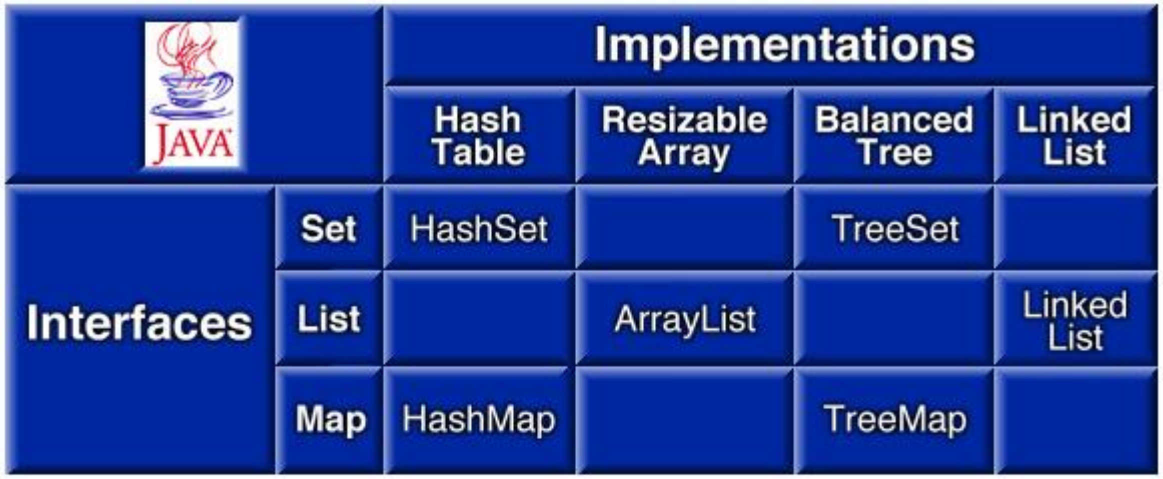
```
// Iterate over all keys in Map m
Map< m;
for (iterator i = m.keySet().iterator(); i.hasNext(); )
    System.out.println(i.next());

// "Map algebra"
Map a, b;
boolean isSubMap = a.entrySet().containsAll(b.entrySet());
Set commonKeys = new HashSet(a.keySet()).retainAll(b.keyset());

//Remove keys from a that have mappings in b
a.keySet().removeAll(b.keySet());
```

General Purpose Implementations

Consistent Naming and Behavior



		Implementations			
		Hash Table	Resizable Array	Balanced Tree	Linked List
Interfaces	Set	HashSet		TreeSet	
	List		ArrayList		Linked List
	Map	HashMap		TreeMap	

Choosing an Implementation

- `Set`
  - `HashSet` -- O(1) access, no order guarantee
  - `TreeSet` -- O(log n) access, sorted
- `Map`
  - `HashMap` -- (See `HashSet`)
  - `TreeMap` -- (See `TreeSet`)
- `List`
  - `ArrayList` -- O(1) random access, O(n) insert/remove
  - `LinkedList` -- O(n) random access, O(1) insert/remove
    - Use for queues and deques (no longer a good idea!)

Implementation Behavior

Unlike `Vector` *and* `Hashtable`…

- Fail-fast iterator
- Null elements, keys, values permitted
- **Not** thread-safe

Synchronization Wrappers

A new approach to thread safety

- Anonymous implementations, one per core interface
- Static factories take collection of appropriate type
- Thread-safety assured if all access through wrapper
- Must manually synchronize iteration
- It was new then; it's old now!
  - Synch wrappers are largely obsolete
  - Made obsolete by concurrent collections

Synchronization Wrapper Example

```
Set s = Collections.synchronizedSet(new HashSet());

        ...

s.add("wombat");  // Thread-safe

        ...

synchronized(s) {
    Iterator i = s.iterator(); // In synch block!
    while (i.hasNext())
        System.out.println(i.next());
}
```

Unmodifiable Wrappers

- Analogous to synchronization wrappers
  - Anonymous implementations
  - Static factory methods
  - One for each core interface
- Provide read-only access

Convenience Implementations

- `Arrays.asList(Object[] a)`
  - Allows array to be "viewed" as List
  - Bridge to Collection-based APIs
- `EMPTY_SET`, `EMPTY_LIST`, `EMPTY_MAP`
  - immutable constants
- `singleton(Object o)`
  - immutable set with specified object
- `nCopies(int n, Object o)`
  - immutable list with n copies of object

Custom Implementation Ideas

- Persistent
- Highly concurrent
- High-performance, special-purpose
- Space-efficient representations
- Fancy data structures
- Convenience classes

Custom Implementation Example

It’s easy with our abstract implementations

```
// List adapter for primitive int array
public static List intArrayList(int[] a) {
    return new AbstractList() {
        public Integer get(int i) {
            return new Integer(a[i]);
        }

        public int size() { return a.length; }

        public Object set(int i, Integer e) {
            int oldVal = a[i];
            a[i] = e.intValue();
            return new Integer(oldVal);
        }
    };
}
```

Reusable Algorithms

```
static void sort(List list);
static int binarySearch(List list, Object key);
static Object min(Collection coll);
static Object max(Collection coll);
static void fill(List list, Object e);
static void copy(List dest, List src);
static void reverse(List list);
static void shuffle(List list);
```

Algorithm Example 1

Sorting lists of comparable elements

```
List strings;                 // Elements type: String
    ...
Collections.sort(strings); // Alphabetical order

List dates;                   // Elements type: Date
    ...
Collections.sort(dates);   // Chronological order


// Comparable interface (Infrastructure)
public interface Comparable {
    int compareTo(Object o);
}
```

Comparator Interface

Infrastructure

- Specifies order among objects
  - Overrides natural order on comparables
  - Provides order on non-comparables

```
public interface Comparator {
    public int compare(Object o1, Object o2);
}
```

Algorithm Example 2

Sorting with a comparator

```
List strings; // Element type: String

Collections.sort(strings, Collections.ReverseOrder());


// Case-independent alphabetical order
static Comparator cia = new Comparator() {
    public int compare(String c1, String c2) {
        return c1.toLowerCase().compareTo(c2.toLowerCase());
    }
};


Collections.sort(strings, cia);
```

Compatibility

Old and new collections interoperate freely

- Upward Compatibility
  - `Vector implements List`
  - `Hashtable implements Map`
  - `Arrays.asList(myArray)`
- Backward Compatibility
  - `myCollection.toArray()`
  - `new Vector(myCollection)`
  - `new Hashtable(myMap)`

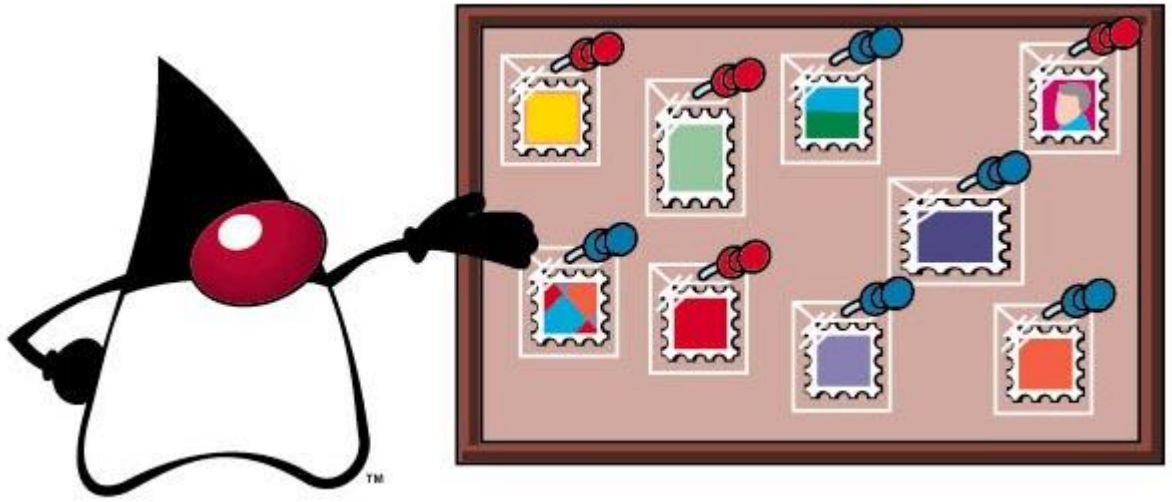
API Design Guidelines

- Avoid ad hoc collections
  - Input parameter type:
    - Any collection **interface** (`Collection`, `Map` best)
    - Array may sometimes be preferable
  - Output value type:
    - Any collection **interface** or **class**
    - Array
- Provide adapters for your legacy collections

Sermon

- Programmers:
  - Use new implementations and algorithms
  - Write reusable algorithms
  - Implement custom collections
- API Designers:
  - Take collection interface objects as input
  - Furnish collections as output

For More Information



http://java.sun.com/products/jdk/1.2/docs/guide/collections/index.html

Takeaways

- Collections haven't changed that much since '98
- API has grown, but essential character unchanged
  - With arguable exception of Java 8 streams (2014)

Part 2: Outline

I. The initial release of the collections API

II. Design of the first release

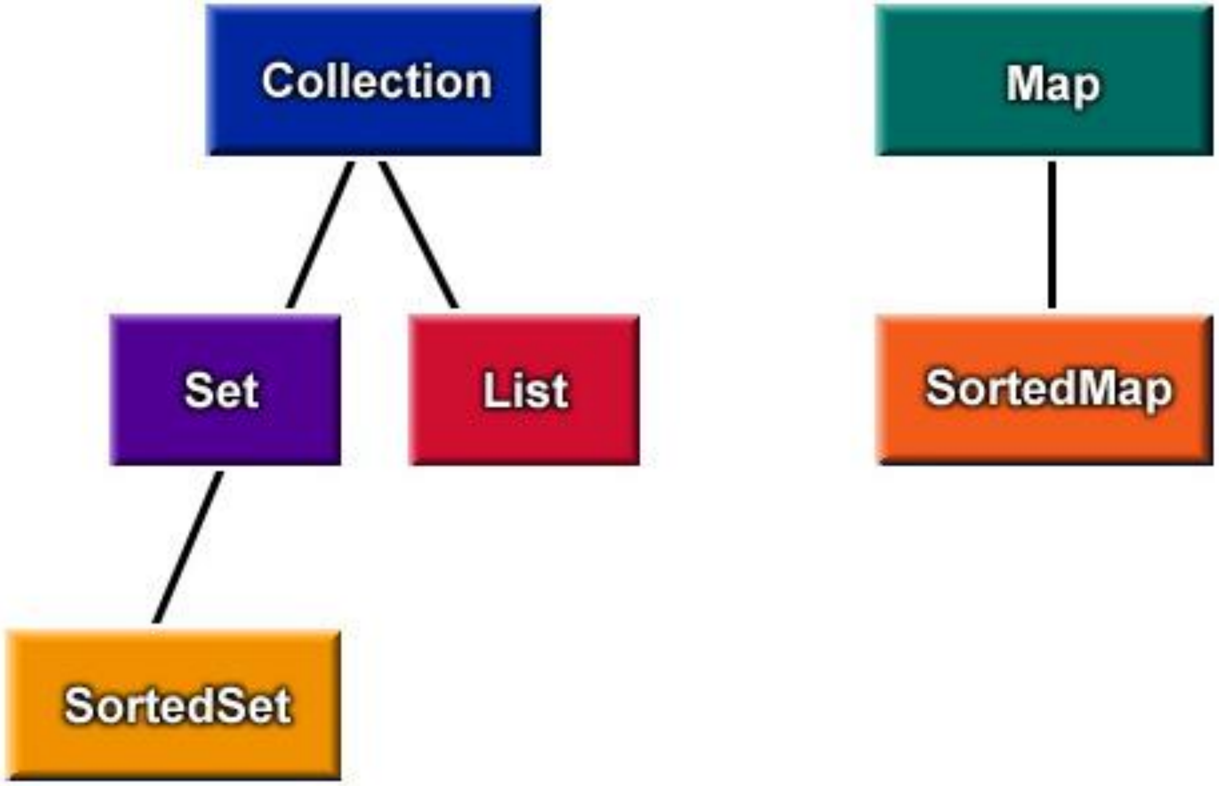
III. Evolution

IV. Code example

V. Critique

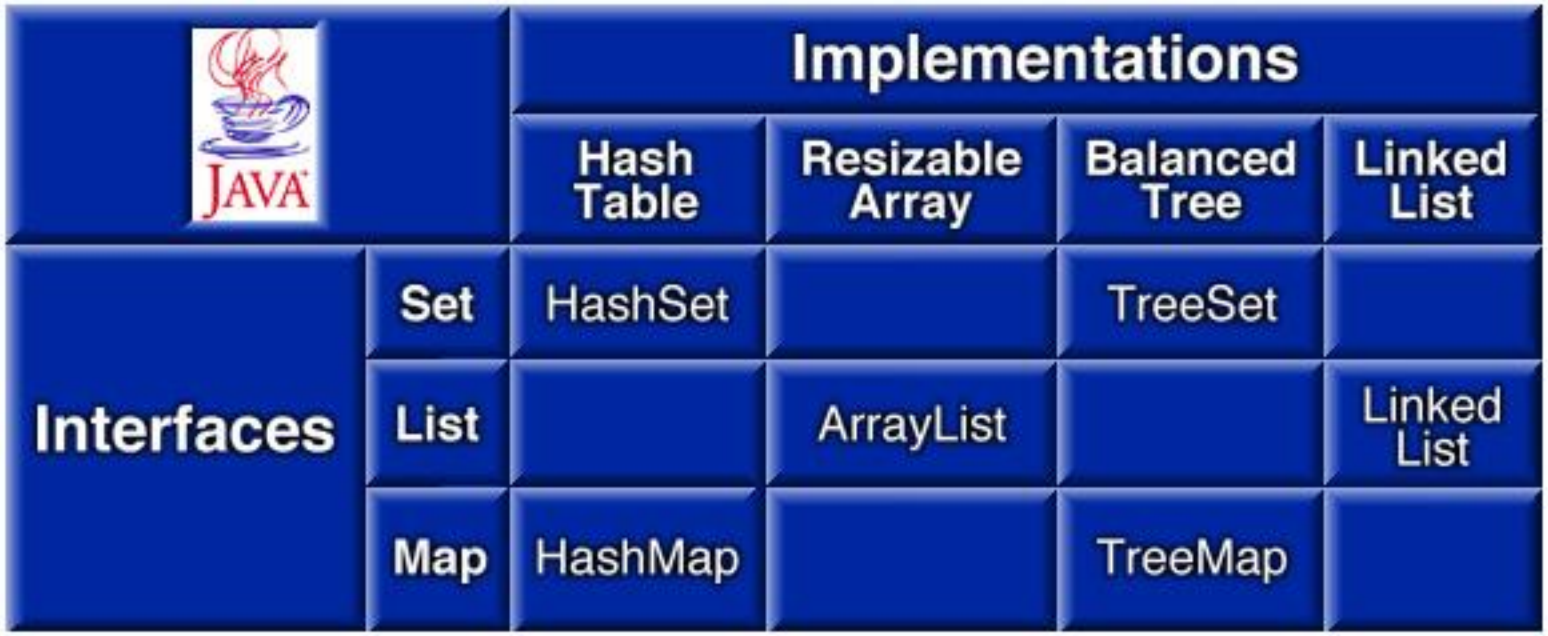
Collection **interfaces**

first release, 1998



General-purpose **implementations**

first release, 1998



		Implementations			
		Hash Table	Resizable Array	Balanced Tree	Linked List
Interfaces	Set	HashSet		TreeSet	
	List		ArrayList		Linked List
	Map	HashMap		TreeMap	

Other **implementations**

first release, 1998

- Convenience implementations
  - `Arrays.asList(Object[] a)`
  - `EMPTY_SET, EMPTY_LIST, EMPTY_MAP`
  - `singleton(Object o)`
  - `nCopies(Object o)`
- Decorator implementations
  - `Unmodifiable{Collection,Set,List,Map,SortedMap}`
  - `Synchronized{Collection,Set,List,Map,SortedMap}`
- Special Purpose implementation – `WeakHashMap`

Reusable **algorithms**
first release, 1998

- `static void sort(List[]);`
- `static int binarySearch(List list, Object key);`
- `static object min(List[]);`
- `static object max(List[]);`
- `static void fill(List list, Object o);`
- `static void copy(List dest, List src);`
- `static void reverse(List list);`
- `static void shuffle(List list);`

Infrastructural interfaces

- `Iterator`
- `ListIterator`
- `Map.Entry`
- `Comarable`
- `Comaprator`

And that's all there was to it!

OK, I told a little white lie: Array utilities, *first release, 1998*

- `static int binarySearch(`*type*`[] a, `*type*` key)`
- `static int binarySearch(Object[] a, Object key, Comparator c)`
- `static boolean equals(`*type*`[] a, `*type*`[] a2)`
- `static void fill(`*type*`[] a, `*type*` val)`
- `static void fill(`*type*`[] a, int fromIndex, int toIndex, `*type*` val)`
- `static void sort(`*type*`[] a)`
- `static void sort(`*type*`[] a, int fromIndex, int toIndex)`
- `static void sort(Object[] a, Comparator c)`
- `static void sort(`*type*`[] a, int fromIdx, int toIdx, Comparator c)`

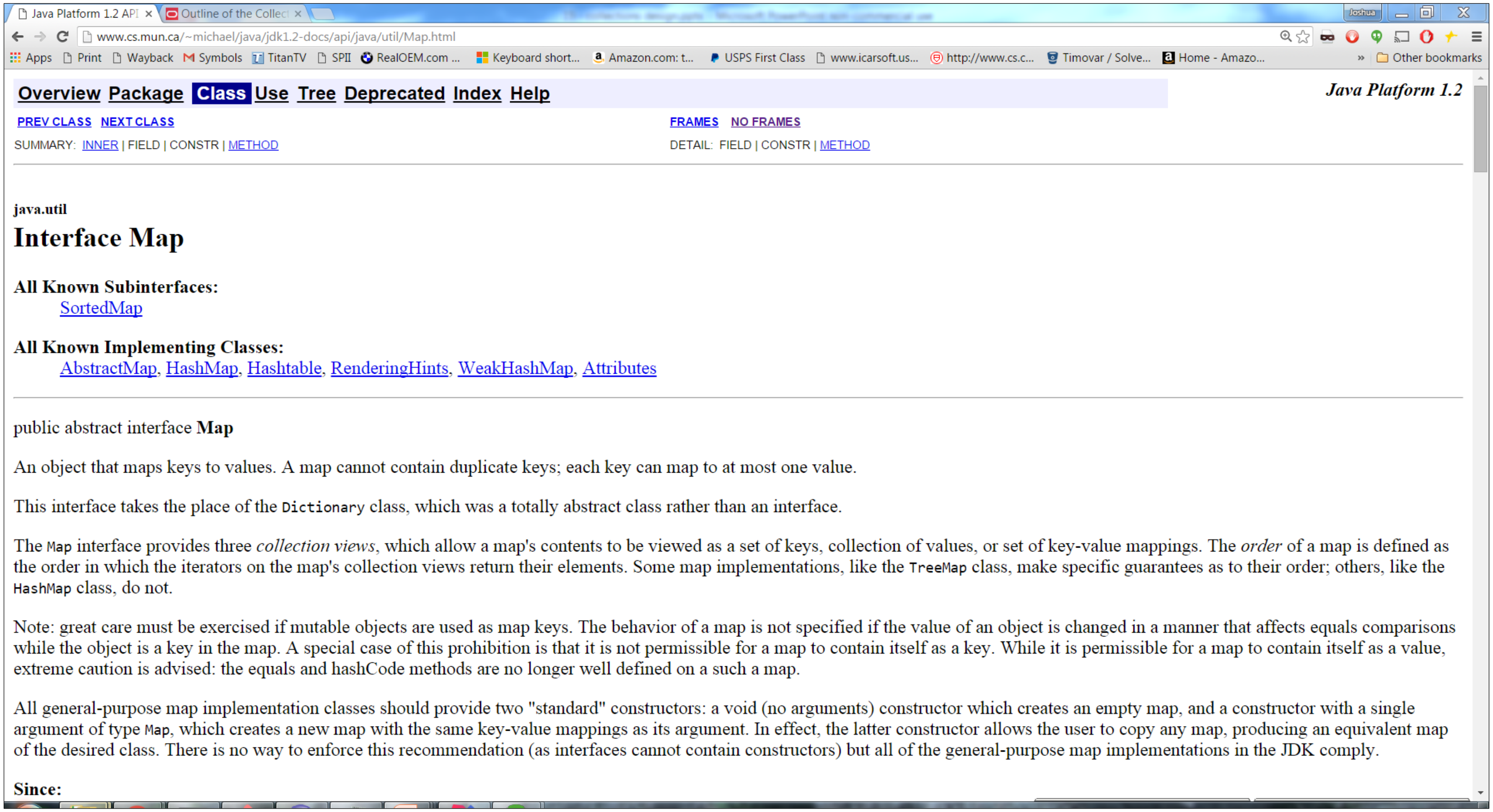
Documentation matters

Reuse is something that is far easier to say than to do. Doing it requires both good design and very good documentation. Even when we see good design, which is still infrequently, we won't see the components reused without good documentation.

- D. L. Parnas, *Software Aging. Proceedings of the 16th International Conference on Software Engineering, 1994*

Of course you need good JavaDoc

But it is not sufficient for a substantial API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Java Platform 1.2
PREV CLASS NEXT CLASS
FRAMES NO FRAMES
SUMMARY: INNER | FIELD | CONSTR | METHOD
DETAIL: FIELD | CONSTR | METHOD

java.util

Interface Map

All Known Subinterfaces:
SortedMap

All Known Implementing Classes:
AbstractMap, HashMap, Hashtable, RenderingHints, WeakHashMap, Attributes

public abstract interface **Map**

An object that maps keys to values. A map cannot contain duplicate keys; each key can map to at most one value.

This interface takes the place of the `Dictionary` class, which was a totally abstract class rather than an interface.

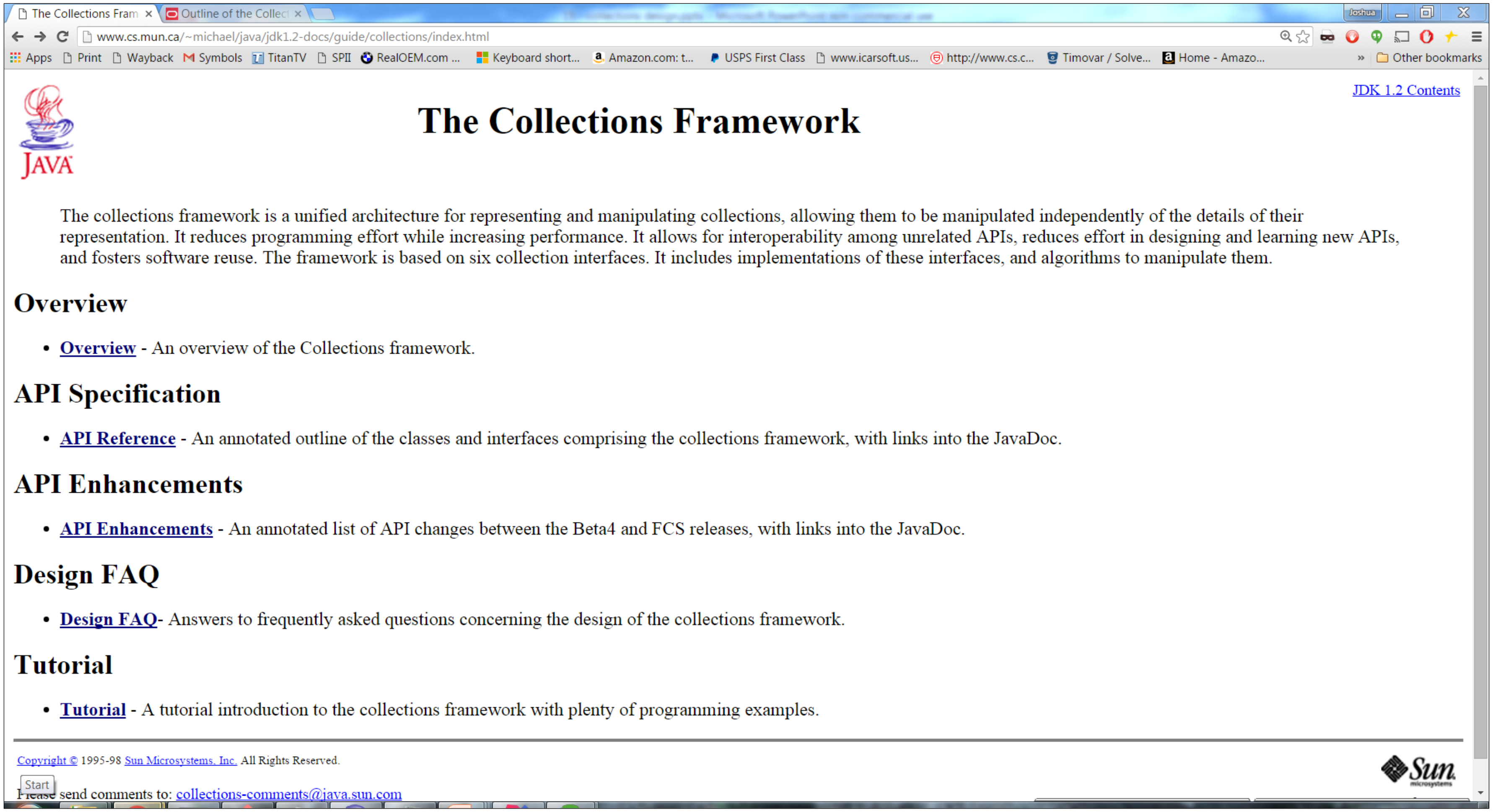
The `Map` interface provides three *collection views*, which allow a map's contents to be viewed as a set of keys, collection of values, or set of key-value mappings. The *order* of a map is defined as the order in which the iterators on the map's collection views return their elements. Some map implementations, like the `TreeMap` class, make specific guarantees as to their order; others, like the `HashMap` class, do not.

Note: great care must be exercised if mutable objects are used as map keys. The behavior of a map is not specified if the value of an object is changed in a manner that affects equals comparisons while the object is a key in the map. A special case of this prohibition is that it is not permissible for a map to contain itself as a key. While it is permissible for a map to contain itself as a value, extreme caution is advised: the equals and hashCode methods are no longer well defined on a such a map.

All general-purpose map implementation classes should provide two "standard" constructors: a void (no arguments) constructor which creates an empty map, and a constructor with a single argument of type `Map`, which creates a new map with the same key-value mappings as its argument. In effect, the latter constructor allows the user to copy any map, producing an equivalent map of the desired class. There is no way to enforce this recommendation (as interfaces cannot contain constructors) but all of the general-purpose map implementations in the JDK comply.

Since:

A single place to go for documentation



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www.cs.mun.ca/~michael/java/jdk1.2-docs/guide/collections/index.html

JDK 1.2 Contents

The Collections Framework

The collections framework is a unified architecture for representing and manipulating collections, allowing them to be manipulated independently of the details of their representation. It reduces programming effort while increasing performance. It allows for interoperability among unrelated APIs, reduces effort in designing and learning new APIs, and fosters software reuse. The framework is based on six collection interfaces. It includes implementations of these interfaces, and algorithms to manipulate them.

Overview

- **Overview** - An overview of the Collections framework.

API Specification

- **API Reference** - An annotated outline of the classes and interfaces comprising the collections framework, with links into the JavaDoc.

API Enhancements

- **API Enhancements** - An annotated list of API changes between the Beta4 and FCS releases, with links into the JavaDoc.

Design FAQ

- **Design FAQ**- Answers to frequently asked questions concerning the design of the collections framework.

Tutorial

- **Tutorial** - A tutorial introduction to the collections framework with plenty of programming examples.

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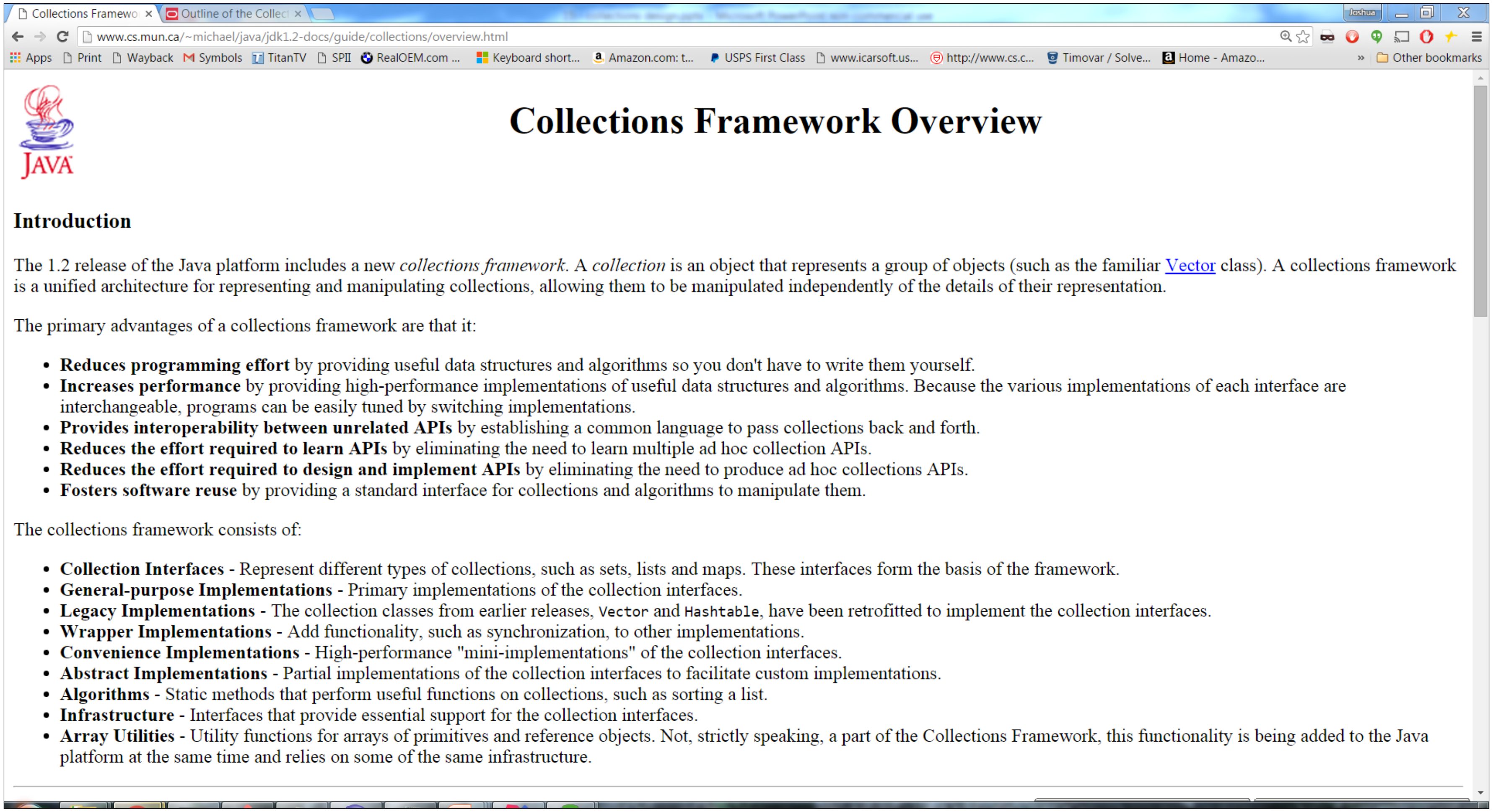
Please send comments to: collections-comments@java.sun.com

Overviews provide understanding

A place to go when first learning an API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JAVA

Collections Framework Overview

Introduction

The 1.2 release of the Java platform includes a new *collections framework*. A *collection* is an object that represents a group of objects (such as the familiar Vector class). A collections framework is a unified architecture for representing and manipulating collections, allowing them to be manipulated independently of the details of their representation.

The primary advantages of a collections framework are that it:

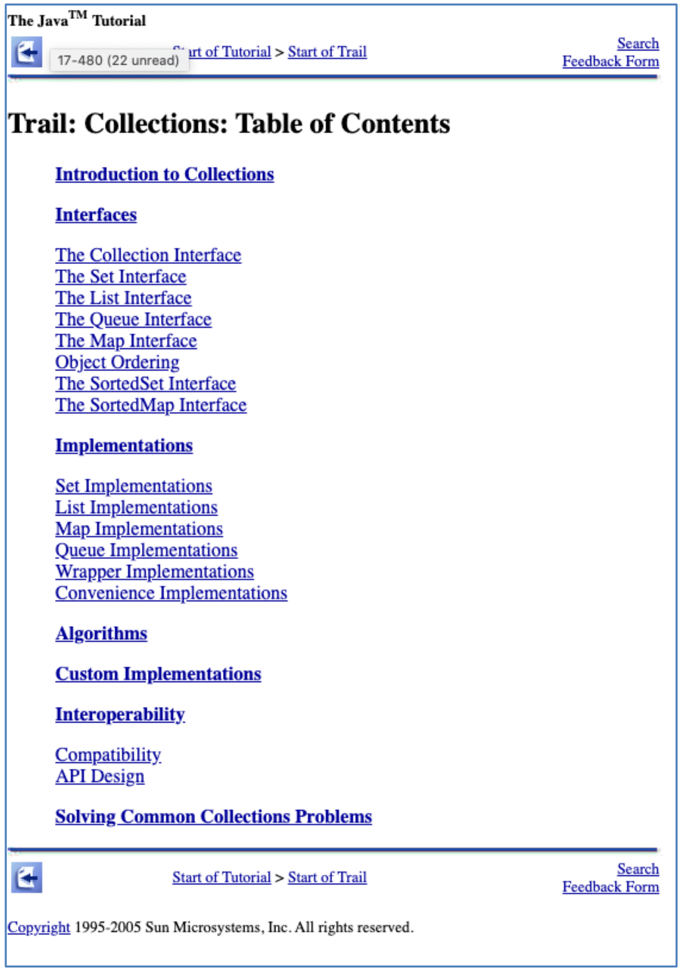
- **Reduces programming effort** by providing useful data structures and algorithms so you don't have to write them yourself.
- **Increases performance** by providing high-performance implementations of useful data structures and algorithms. Because the various implementations of each interface are interchangeable, programs can be easily tuned by switching implementations.
- **Provides interoperability between unrelated APIs** by establishing a common language to pass collections back and forth.
- **Reduces the effort required to learn APIs** by eliminating the need to learn multiple ad hoc collection APIs.
- **Reduces the effort required to design and implement APIs** by eliminating the need to produce ad hoc collections APIs.
- **Fosters software reuse** by providing a standard interface for collections and algorithms to manipulate them.

The collections framework consists of:

- **Collection Interfaces** - Represent different types of collections, such as sets, lists and maps. These interfaces form the basis of the framework.
- **General-purpose Implementations** - Primary implementations of the collection interfaces.
- **Legacy Implementations** - The collection classes from earlier releases, `Vector` and `Hashtable`, have been retrofitted to implement the collection interfaces.
- **Wrapper Implementations** - Add functionality, such as synchronization, to other implementations.
- **Convenience Implementations** - High-performance "mini-implementations" of the collection interfaces.
- **Abstract Implementations** - Partial implementations of the collection interfaces to facilitate custom implementations.
- **Algorithms** - Static methods that perform useful functions on collections, such as sorting a list.
- **Infrastructure** - Interfaces that provide essential support for the collection interfaces.
- **Array Utilities** - Utility functions for arrays of primitives and reference objects. Not, strictly speaking, a part of the Collections Framework, this functionality is being added to the Java platform at the same time and relies on some of the same infrastructure.

Tutorials teach

Another place to go when learning an API



The Java^{TM} Tutorial

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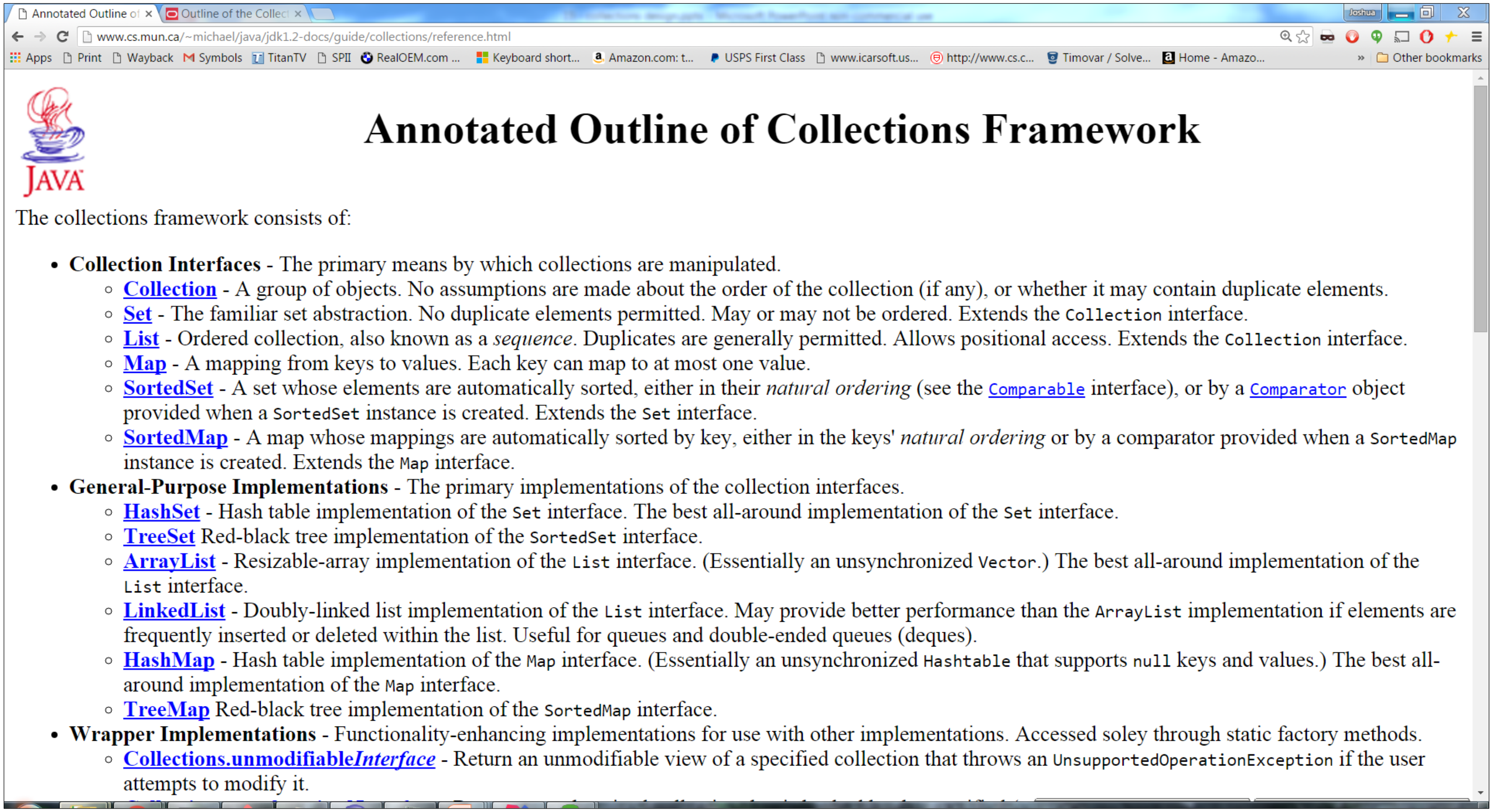
Annotated outlines provide access

I like them, but not everyone does

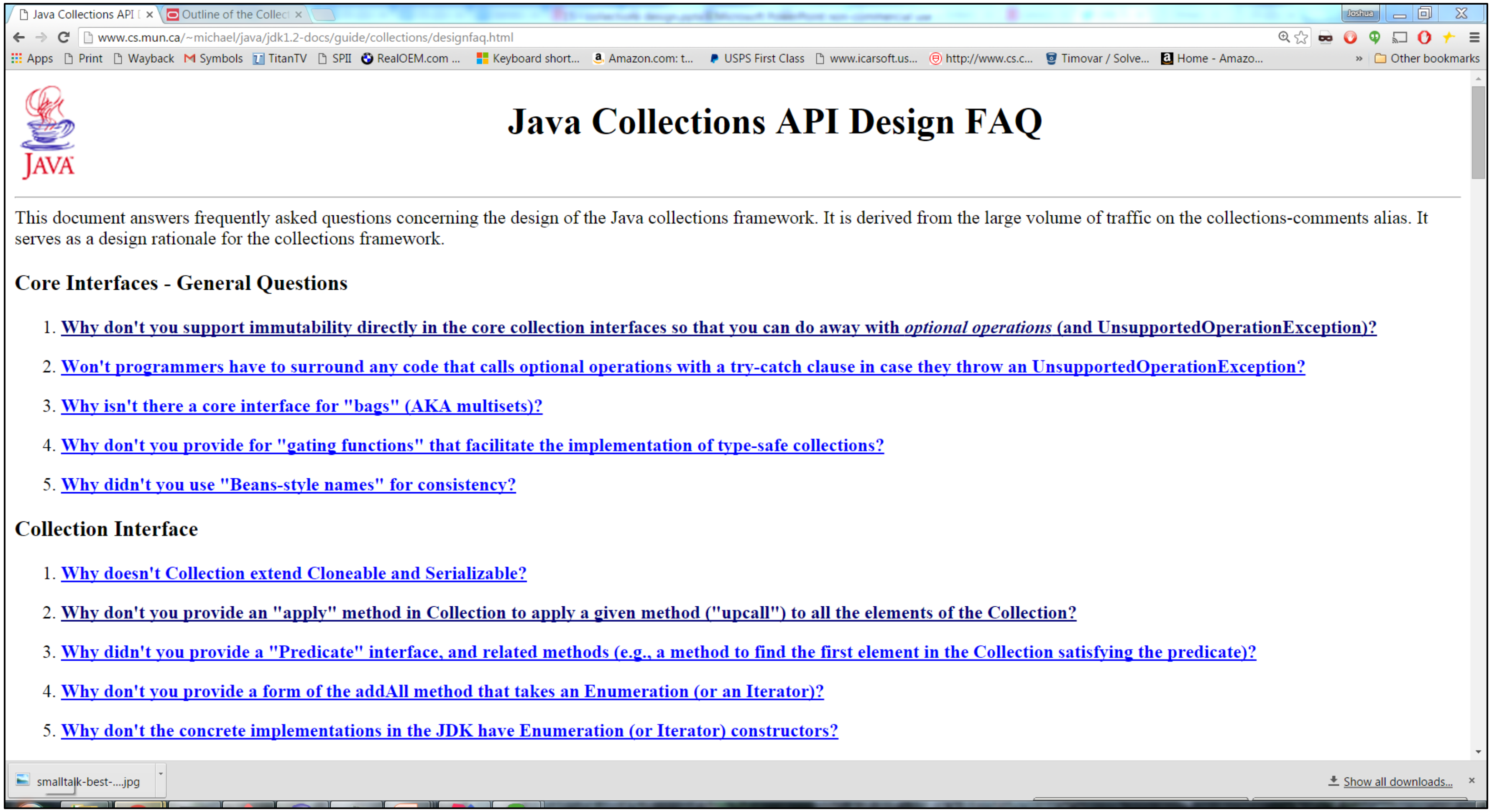


Annotated Outline of Collections Framework

The collections framework consists of:

- **Collection Interfaces** - The primary means by which collections are manipulated.
  - Collection - A group of objects. No assumptions are made about the order of the collection (if any), or whether it may contain duplicate elements.
  - Set - The familiar set abstraction. No duplicate elements permitted. May or may not be ordered. Extends the `Collection` interface.
  - List - Ordered collection, also known as a *sequence*. Duplicates are generally permitted. Allows positional access. Extends the `Collection` interface.
  - Map - A mapping from keys to values. Each key can map to at most one value.
  - SortedSet - A set whose elements are automatically sorted, either in their *natural ordering* (see the `Comparable` interface), or by a `Comparator` object provided when a `SortedSet` instance is created. Extends the `Set` interface.
  - SortedMap - A map whose mappings are automatically sorted by key, either in the keys' *natural ordering* or by a comparator provided when a `SortedMap` instance is created. Extends the `Map` interface.
- **General-Purpose Implementations** - The primary implementations of the collection interfaces.
  - HashSet - Hash table implementation of the `Set` interface. The best all-around implementation of the `Set` interface.
  - TreeSet Red-black tree implementation of the `SortedSet` interface.
  - ArrayList - Resizable-array implementation of the `List` interface. (Essentially an unsynchronized `Vector`.) The best all-around implementation of the `List` interface.
  - LinkedList - Doubly-linked list implementation of the `List` interface. May provide better performance than the `ArrayList` implementation if elements are frequently inserted or deleted within the list. Useful for queues and double-ended queues (deques).
  - HashMap - Hash table implementation of the `Map` interface. (Essentially an unsynchronized `Hashtable` that supports `null` keys and values.) The best all-around implementation of the `Map` interface.
  - TreeMap Red-black tree implementation of the `SortedMap` interface.
- **Wrapper Implementations** - Functionality-enhancing implementations for use with other implementations. Accessed soley through static factory methods.
  - Collections.unmodifiable*Interface* - Return an unmodifiable view of a specified collection that throws an `UnsupportedOperationException` if the user attempts to modify it.

A design rationale saves you hassle
and provides a testament to history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www.cs.mun.ca/~michael/java/jdk1.2-docs/guide/collections/designfaq.html

Java Collections API Design FAQ

This document answers frequently asked questions concerning the design of the Java collections framework. It is derived from the large volume of traffic on the collections-comments alias. It serves as a design rationale for the collections framework.

Core Interfaces - General Questions

1. Why don't you support immutability directly in the core collection interfaces so that you can do away with *optional operations* (and UnsupportedOperationException)?
2. Won't programmers have to surround any code that calls optional operations with a try-catch clause in case they throw an UnsupportedOperationException?
3. Why isn't there a core interface for "bags" (AKA multisets)?
4. Why don't you provide for "gating functions" that facilitate the implementation of type-safe collections?
5. Why didn't you use "Beans-style names" for consistency?

Collection Interface

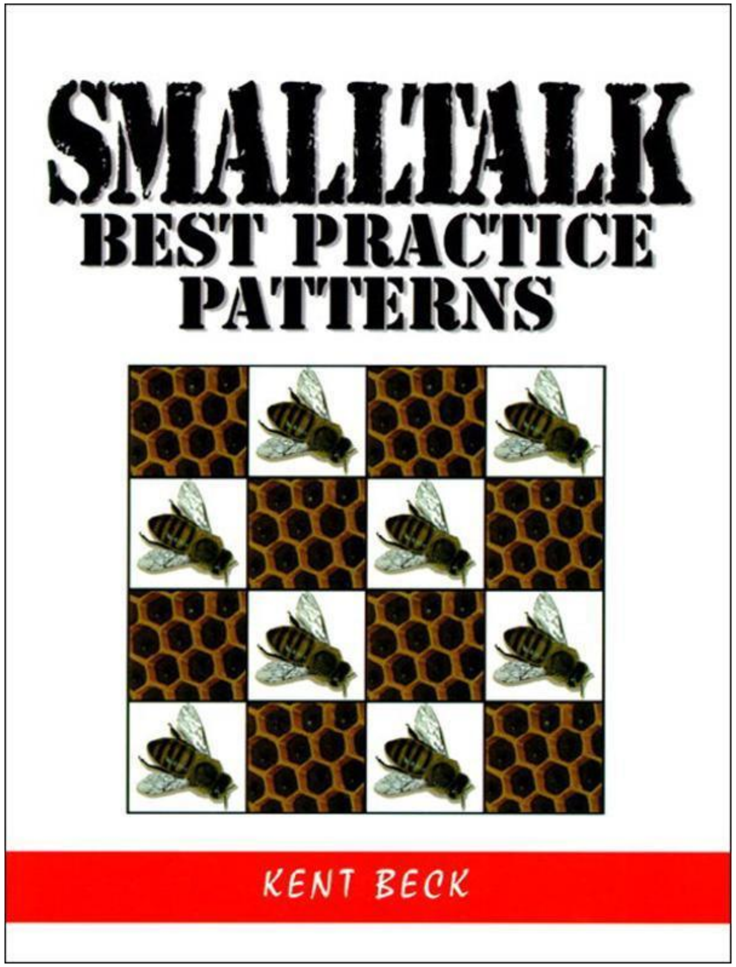
1. Why doesn't Collection extend Cloneable and Serializable?
2. Why don't you provide an "apply" method in Collection to apply a given method ("upcall") to all the elements of the Collection?
3. Why didn't you provide a "Predicate" interface, and related methods (e.g., a method to find the first element in the Collection satisfying the predicate)?
4. Why don't you provide a form of the addAll method that takes an Enumeration (or an Iterator)?
5. Why don't the concrete implementations in the JDK have Enumeration (or Iterator) constructors?

Outline

I. The initial release of the collections API
II. Design of the first release
III. Evolution
IV. Code example
V. Critique

A wonderful source of use cases

"Good artists copy, great artists steal." – Pablo Picasso



The first draft of API was not so nice

- Map was called `Table`
- No `HashMap`, only `Hashtable`
- No algorithms (`Collections`, `Arrays`)
- Contained some unbelievable garbage

Automatic alias detection
A horrible idea that died on the vine

```
/**
 * This interface must be implemented by Collections and Tables that are
 * <i>views</i> on some backing collection.  (It is necessary to
 * implement this interface only if the backing collection is not
 * <i>encapsulated</i> by this Collection or Table; that is, if the
 * backing collection might conceivably be be accessed in some way other
 * than through this Collection or Table.)  This allows users
 * to detect potential <i>aliasing</i> between collections.
 * <p>
 * If a user attempts to modify one collection
 * object while iterating over another, and they are in fact views on
 * the same backing object, the iteration may behave erratically.
 * However, these problems can be prevented by recognizing the
 * situation, and "defensively copying" the Collection over which
 * iteration is to take place, prior to the iteration.
 */

public interface Alias {
    /**
     * Returns the identityHashCode of the object "ultimately backing" this
     * collection, or zero if the backing object is undefined or unknown.
     * The purpose of this method is to allow the programmer to determine
     * when the possiblity of <i>aliasing</i> exists between two collections
     * (in other words, modifying one collection could affect the other).
       This
     * is critical if the programmer wants to iterate over one collection and
     * modify another; if the two collections are aliases, the effects of
     * the iteration are undefined, and it could loop forever.  To avoid
     * this behavior, the careful programmer must "defensively copy" the
     * collection prior to iterating over it whenver the possibility of
     * aliasing exists.
     * <p>
     * If this collection is a view on an Object that does not impelement
     * Alias, this method must return the IdentityHashCode of the backing
     * Object.  For example, a List backed by a user-provided array would
     * return the IdentityHashCode of the array.
     * If this collection is a <i>view</i> on another Object that implements
     * Alias, this method must return the backingObjectId of the backing
     * Object.  (To avoid the cost of recursive calls to this method, the
     * backingObjectId may be cached at creation time).
     * <p>
     * For all collections backed by a particular "external data source" (a
     * SQL database, for example), this method must return the same value.
     * The IdentityHashCode of a "proxy" Object created just for this
     * purpose will do nicely, as will a pseudo-random integer permanently
     * associated with the external data source.
     * <p>
     * For any collection backed by multiple Objects (a "concatenation
     * view" of two Lists, for instance), this method must return zero.
     * Similarly, for any <i>view</i> collection for which it cannot be
     * determined what Object backs the collection, this method must return
     * zero.  It is always safe for a collection to return zero as its
     * backingObjectId, but doing so when it is not necessary will lead to
     * inefficiency.
     *  <p>
     * The possibility of aliasing between two collections exists iff
     * any of the following conditions are true:<ol>
     *           <li>The two collections are the same Object.
     *           <li>Either collection implements Alias and has a
     *               backingObjectId that is the identityHashCode of
     *               the other collection.
     *           <li>Either collection implements Alias and has a
     *               backingObjectId of zero.
     *           <li>Both collections implement Alias and they have equal
     *               backingObjectId's.</ol>
     *
     * @see java.lang.System#identityHashCode
     * @since JDK1.2
     */
    int backingObjectId();
}
```

I received a *lot* of feedback

- Initially from a small circle of colleagues
  - Some *very* good advice
  - Some not so good
- Then from the public at large: beta releases
  - Hundreds of messages
  - Many API flaws were fixed in this stage
  - I put up with a lot of flaming

Review from a ***very*** senior engineer

API	vote	notes
Arrays	yes	But remove binarySearch* and toList
BasicCollection	no	I don't expect lots of collection classes
BasicList	no	see List below
Collection	yes	But cut toArray
Comparator	no	
DoublyLinkedList	no	(without generics this isn't worth it)
HashSet	no	
LinkedList	no	(without generics this isn't worth it)
List	no	I'd like to say yes, but it's just way bigger than I was expecting
RemovalEnumeration	no	
Table	yes	BUT IT NEEDS A DIFFERENT NAME
TreeSet	no	

I'm generally not keen on the toArray methods because they add complexity

Simiarly, I don't think that the table Entry subclass or the various views mechanisms carry their weight.

III. Evolution of Java collections

Release, Year	Changes
JDK 1.0, 1996	Java Released: `Vector`, `Hashtable`, `Enumeration`
JDK 1.1, 1996	(No API changes)
J2SE 1.2, 1998	Collections framework added
J2SE 1.3, 2000	(No API changes)
J2SE 1.4, 2002	`LinkedHash{Map,Set}`, `IdentityHashSet`, 6 new algorithms
J2SE 5.0, 2004	Generics, for-each, enums: generified everything, `Iterable` `Queue`, `Enum{Set,Map}`, concurrent collections
Java 6, 2006	`Deque`, `Navigable{Set,Map}`, `newSetFromMap`, `asLifoQueue`
Java 7, 2011	No API changes. Improved sorts & defensive hashing
Java 8, 2014	Lambdas (+ streams and internal iterators)
Java 9, 2017	Immutable collection factories, e.g. `List.of(G, A, T, A, C)`

IV. Example – How to find anagrams

- Alphabetize the characters in each word
  - e.g., 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 (1/2)

```
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 alphagram = alphabetize(word);
            List<String> group = groups.get(alphagram);
            if (group == null)
                groups.put(alphagram, group = new ArrayList<>());
            group.add(word);
        }
    }
```

How to find anagrams in Java (2/2)

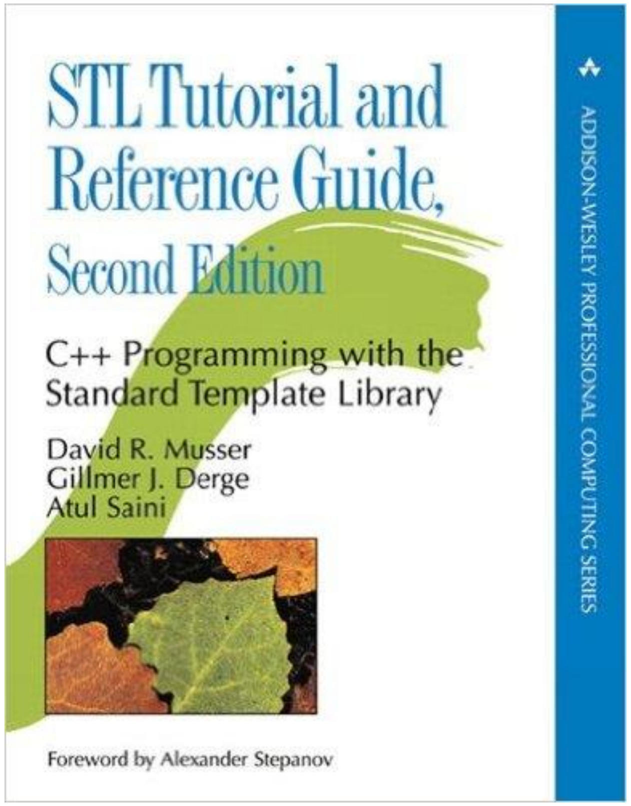
```
    // Print all anagram groups above size threshold
    int minGroupSize = Integer.parseInt(args[1]);
    for (List<String> group : groups.values())
        if (group.size() >= minGroupSize)
            System.out.println(group.size() + ": " + group);
}

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

Demo – Anagrams

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

Java's verbosity is somewhat exaggerated


STL Tutorial and Reference Guide, Second Edition

C++ Programming with the Standard Template Library

David R. Musser
Gillmer J. Derge
Atul Saini

Foreword by Alexander Stepanov

ADDISON-WESLEY PROFESSIONAL COMPUTING SERIES

P.S. Here's how it looks with streams

The entire anagrams program fits easily on a slide

```
public static void main(String[] args) throws IOException {
    Path dictionary = Paths.get(args[0]);
    int minGroupSize = Integer.parseInt(args[1]);

    try (Stream<String> words = Files.lines(dictionary)) {
        words.collect(groupingBy(word -> alphabetize(word)))
            .values().stream()
            .filter(group -> group.size() >= minGroupSize)
            .forEach(g -> System.out.println(g.size() + ": " + g));
}

private static String alphabetize(String s) {
    char[] a = s.toCharArray();
    Arrays.sort(a);
    return new String(a);
}
```

V. Critique

Some things I wish I'd done differently

- Algorithms should return collection, not void or boolean
  - Turns ugly multiliners into nice one-liners

```
private static String alphabetize(String s) {
    return new String(Arrays.sort(s.toCharArray()));
}
```

- Sorted{Set,Map} should have had proper navigation
  - Navigable{Set,Map} are warts
- Should not have bothered with `ListIterator` (?)
- Should have fought for `map[key]`, `list[]`
- Should have fought to incorporate arrays
- Should have fought to make for-each work on String
- Etc., Etc., Etc.

Conclusion

- **It takes a lot of work to make something that appears obvious in retrospect**
  – Coherent, unified vision, built on a few key concepts
  – Willingness to listen to others
  – Flexibility to accept change
  – Tenacity to resist change
  – Good documentation!
- **It's worth the effort!**
  – A solid foundation can last two+ decades