Collections Refueled

Collections Framework Enhancements in Java 9

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Java
Your
Next
(Cloud)

Collections Refueled

- Brief History of Collections
- Java 8 Collections Enhancements
- Java 9 Collections Enhancements

(Almost) Twenty Years of Java Collections

- JDK 1.0 – 1996
  - "Legacy Collections"
  - Vector, Hashtable, Enumeration, Dictionary, Stack
- JDK 1.2 – 1998
  - Collections Framework introduced
  - interfaces: Collection, List, Set, Map, Iterator, Comparable, Comparator, SortedSet, SortedMap
  - concrete classes: ArrayList, HashSet, HashMap, TreeSet, TreeMap, WeakHashMap
- JDK 1.4 – 2002
  - IdentityHashMap, LinkedHashSet, LinkedHashMap

(Almost) Twenty Years of Java Collections

- Java SE 5.0 – 2004
  - generics introduced, collections generified
  - Iterable, Queue, PriorityQueue, EnumSet, EnumMap
  - java.util.concurrent
    - ConcurrentHashMap, CopyOnWriteArrayList, BlockingQueue, etc.
- Java SE 6 – 2006
  - Deque, ArrayDeque, NavigableSet, NavigableMap (enhanced TreeSet, TreeMap)
- Java SE 7 – 2011
  - TimSort, Collections.emptyIterator ... hardly anything!

Java 8 (2014)

- Lambda/Streams
  - Collections are most common stream source and destination
- Interfaces: Default Methods, Static Methods
  - Java 8 language features
  - allows interfaces to be extended compatibly
- Collection interface enhancements
  - first changes in > 15 years!
  - Iterable, Collection, List got a few new methods
  - Map, Comparator got a lot of new methods
  - Most new methods leverage lambdas and method references
  - Default methods ***enhanced all existing collections***

Java 8 (2014)

- Iterable.forEach
- Iterator.remove
- Iterator.forEachRemaining
- Collection.stream
- Collection.removeIf
- List.replaceAll
- List.sort
- Map.forEach
- Map.replaceAll
- Map.compute
- Map.computeIfAbsent
- Map.computeIfPresent
- Map.getOrDefault
- Comparator.comparing
- Comparator.thenComparing

Java 9 (2017)

- JEP 269 Collections Convenience Factories
  - JEP = “JDK Enhancement Proposal”
  - Static factory methods for creating collections conveniently
  - First new collection implementations since 7, first in java.util since 1.6
- Other enhancements to collections-related classes

JEP 269 – Convenience Factory Methods for Collections

- Library-only alternative to collection literals
  - no language changes
  - gets ~80% of the benefit of language changes at a tiny fraction of the cost
- Main goals
  - convenience and brevity
  - space efficiency
  - immutability
- Uncovered a surprising number of API and implementation issues

JEP 269 – Convenience Factory Methods for Collections

- History & Background
  - Java 7 Project Coin – Collection Literals proposal
  - Post Java 8 – JEP 186 Collection Literals “research JEP”
  - both were proposals to enhance the Java language
- Collections are at “arm’s length” from the Java language
  - many other languages have collections built-in
  - Java’s only built-in aggregation constructs are arrays and classes
  - higher-level collection features are delegated to libraries
  - binding language and collection libraries too tightly created design discomfort

JEP 269 API: Static Methods on Interfaces

```
List.of()
List.of(e1)
List.of(e1, e2)          // fixed-arg overloads up to ten elements
List.of(elements...)     // varargs supports arbitrary number of elements

Set.of()
Set.of(e1)
Set.of(e1, e2)           // fixed-arg overloads up to ten elements
Set.of(elements...)      // varargs supports arbitrary number of elements

Map.of()
Map.of(k1, v1)
Map.of(k1, v1, k2, v2)   // fixed-arg overloads up to ten key-value pairs

Map.ofEntries(entry(k1, v1), entry(k2, v2), ...)     // varargs

Map.entry(k, v)          // creates a Map.Entry instance
```

static <K,V> Map<K,V>	of() Returns an immutable map containing zero mappings.
static <K,V> Map<K,V>	of(K k1, V v1) Returns an immutable map containing a single mapping.
static <K,V> Map<K,V>	of(K k1, V v1, K k2, V v2) Returns an immutable map containing two mappings.
static <K,V> Map<K,V>	of(K k1, V v1, K k2, V v2, K k3, V v3) Returns an immutable map containing three mappings.
static <K,V> Map<K,V>	of(K k1, V v1, K k2, V v2, K k3, V v3, K k4, V v4) Returns an immutable map containing four mappings.
static <K,V> Map<K,V>	of(K k1, V v1, K k2, V v2, K k3, V v3, K k4, V v4, K k5, V v5) Returns an immutable map containing five mappings.
static <K,V> Map<K,V>	of(K k1, V v1, K k2, V v2, K k3, V v3, K k4, V v4, K k5, V v5, K k6, V v6) Returns an immutable map containing six mappings.
static <K,V> Map<K,V>	of(K k1, V v1, K k2, V v2, K k3, V v3, K k4, V v4, K k5, V v5, K k6, V v6, K k7, V v7) Returns an immutable map containing seven mappings.
static <K,V> Map<K,V>	of(K k1, V v1, K k2, V v2, K k3, V v3, K k4, V v4, K k5, V v5, K k6, V v6, K k7, V v7, K k8, V v8) Returns an immutable map containing eight mappings.
static <K,V> Map<K,V>	of(K k1, V v1, K k2, V v2, K k3, V v3, K k4, V v4, K k5, V v5, K k6, V v6, K k7, V v7, K k8, V v8, K k9, V v9) Returns an immutable map containing nine mappings.
static <K,V> Map<K,V>	of(K k1, V v1, K k2, V v2, K k3, V v3, K k4, V v4, K k5, V v5, K k6, V v6, K k7, V v7, K k8, V v8, K k9, V v9, K k10, V v10) Returns an immutable map containing ten mappings.

Examples

```
// Java 8

    List<String> stringList = Arrays.asList("a", "b", "c");
    Set<String> stringSet = new HashSet<>(Arrays.asList("a", "b", "c"));
    Map<String,Integer> stringMap = new HashMap<>();
    stringMap.put("a", 1);
    stringMap.put("b", 2);
    stringMap.put("c", 3);

// Java 9

    List<String> stringList = List.of("a", "b", "c");
    Set<String> stringSet = Set.of("a", "b", "c");
    Map<String,Integer> stringMap = Map.of("a", 1, "b", 2, "c", 3);
```

Example: Map With Arbitrary Number of Pairs

```
Map<String, TokenType> tokens = Map.ofEntries(
    entry("@",     AT),
    entry("|",     VERTICAL_BAR),
    entry("#",     HASH),
    entry("%",     PERCENT),
    entry(":",     COLON),
    entry("^",     CARET),
    entry("&",     AMPERSAND),
    entry("!",     EXCLAM),
    entry("?",     QUESTION),
    entry("$",     DOLLAR),
    entry("::",    PAAMAYIM_NEKUDOTAYIM),
    entry("=",     EQUALS),
    entry(";",     SEMICOLON)
);
```

Design and Implementation Issues

- Handling arbitrary number of mappings
- Immutability, contrast with Unmodifiability
- Iteration Order
- Nulls Disallowed
- Duplicate Handling
- Space Efficiency
- Serializability
- Other Behavior Differences

API Design: Handling Arbitrary Number of Mappings

- List and Set have obvious varargs extensions, not so for Map
- Investigated about 15 different approaches
  - technical evaluation: “they all suck”
  - this is the case where language syntax support would be most helpful
- Criteria
  - simple, little boilerplate
  - compile-time type-safe
  - number of elements known at compile time (avoid resizing/rehashing)
  - each key and value should be adjacent in source code
  - avoid boxing

API Design: Handling Arbitrary Number of Mappings

- Solution: Map.ofEntries(Map.Entry... entries)
- Add Map.entry() static factory method returning Map.Entry
  - suitable for static import; can use

```
entry(key, value)
```

  - instead of

```
new AbstractMap.SimpleImmutableEntry<>(key, value)
```

- Satisfies all criteria except for boxing
  - maybe... the Map.Entry can be turned into a value type in the future
- Overall a reasonable compromise

Immutability

- Collections returned by the new static factory methods are immutable
- "Conventional" immutability, not "immutable persistent"
  - attempts to add, set, or remove throw UnsupportedOperationException
- Immutability is good!
  - common case: collection initialized from known values, never changed
  - automatically thread-safe
  - provides opportunities for efficiency, especially space
- No general-purpose immutable collections exist in the JDK
  - unmodifiable wrappers are a poor substitute

Immutability vs. Unmodifiability

- What's the difference between list1 and list2?

```
List<Integer> temp = Arrays.asList(1, 2, 3);
List<Integer> list1 = Collections.unmodifiableList(temp);
List<Integer> list2 = List.of(1, 2, 3);
```

- Similarities
  - Mutator methods add(), remove(), set() etc. throw UnsupportedOperationException
- Differences
  - list1 is an *unmodifiable view* of the underlying list temp
  - modifications to temp are visible to list1
  - list2 cannot be modified at all
    - except via reflection, but that's cheating

Randomized Iteration Order

- Iteration order for Set elements and Map keys
  - HashSet, HashMap: order is officially unspecified
  - however, usually consistent for long periods of time (> 1 JDK release cycle)
  - inadvertent order dependencies can creep into code
- Lots of code breaks when iteration order is changed
  - occasionally necessary to improve performance or fix security holes
  - lots of code probably has latent iteration order dependencies (i.e., bugs!)
  - "just change this HashMap to a LinkedHashMap" – random bugs disappear

Randomized Iteration Order

- Solution: randomized iteration order for JEP 269 collections
  - make iteration order predictably unpredictable!
  - iteration order will be stable within a JVM instance
  - but will change from one run to the next
- Precedents: Go language; Python 3.0 – 3.5
- Goal: "toughen up" user code to prevent iteration order dependencies
  - bugs flushed out in development and test, before production (we hope)
- Applies only to new collections implementations
  - by definition, no existing code depends on their iteration order
  - existing collections will remain the same

Nulls Disallowed

- Nulls disallowed as List or Set members, Map keys or values
  - NullPointerException thrown at creation time
- Allowing nulls in collections back in 1.2 was a mistake
  - no collection in Java 5 or later has permitted nulls
  - particularly the java.util.concurrent collections
- Why not?
  - nulls are bad! source of NPEs
  - nulls useful as sentinel values in APIs, e.g., Map.get(), Map.compute()
  - nulls useful as sentinel values for optimizing implementations

Throw Exceptions on Duplicates

- Duplicate set elements or map keys throw IllegalArgumentException
- Duplicates in a “collection literal” are most likely a programming error
- Ideally this would be detected at compile time
  - values aren’t compile-time constants
  - next best thing: fail-fast on creation at runtime
- Very few other systems do this
  - most are “last one wins”
  - Clojure and ECMAScript (strict) are notable outliers

Example: Map With Duplicate Keys

```
Map<String, TokenType> tokens = Map.ofEntries(
    entry("@",     AT),
    entry("|",     VERTICAL_BAR),
    entry("#",     HASH),
    entry("%",     PERCENT),
    entry(":",     COLON),
    entry("^",     CARET),
    entry("&",     AMPERSAND),
    entry("|",     EXCLAM),
    entry("?",     QUESTION),
    entry("$",     DOLLAR),
    entry("::",    PAAMAYIM_NEKUDOTAYIM),
    entry("=",     EQUALS),
    entry(";",     SEMICOLON)
);
```

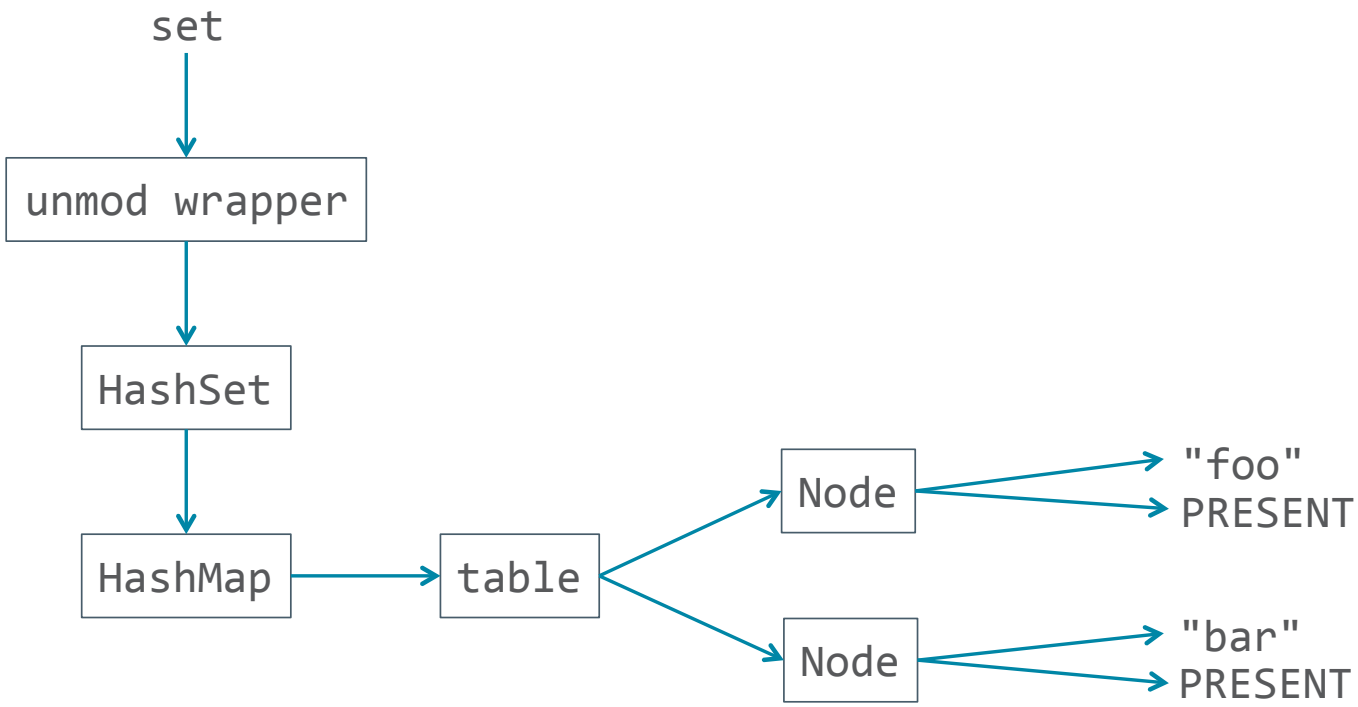
Space Efficiency

- Consider an unmodifiable set containing two strings

```
Set<String> set = new HashSet<>(3);  // 3 is the number of buckets
set.add("foo");
set.add("bar");
set = Collections.unmodifiableSet(set);
```

- How much space does this take? Count objects.
  - 1 unmodifiable wrapper
  - 1 HashSet
  - 1 HashMap
  - 1 Object[] table of length 3
  - 2 Node objects, one for each element

Space Efficiency



Space Efficiency

- Size estimate
  - 12 byte header per object
  - (assume 64-bit JVM with compressed OOPS)
  - plus 4 bytes per int, float, or reference field
- Object sizes
  - unmod wrapper: header + 1 field = 16 bytes
  - HashSet: header + 1 field = 16 bytes
  - HashMap: header + 6 fields = 36 bytes
  - table: header + 4 fields = 28 bytes
  - Node: header + 4 fields = 28 bytes x 2 = 56 bytes

Total 152 bytes to store two object references!

Space Efficiency

- Field-based set implementation

```
Set<String> set = Set.of("foo", "bar");
```

- One object, two fields
  - 20 bytes, compared to 152 bytes for conventional structure
- Efficiency gains
  - lower fixed cost: fewer objects created for a collection of any size
  - lower variable cost: fewer bytes overhead per collection element

Multiple Implementations

- All implementations are private classes hidden behind static factory
  - static factory method chooses the implementation class based on size
- Different data organizations
  - field-based implementations
    - specialized implementations for 0, 1, 2, ... elements
  - array-based with closed hashing
  - can be changed compatibly even in minor releases
- Benefits
  - less space overall
  - fewer objects result in improved locality of reference

Serialization

- All collections will be serializable
  - yes, people really use serialization
  - default serialized form would “leak” information about internal implementation
    - this can be a compatibility issue if you’re not careful
- New collections implementations will have custom serial form
  - serialization emits serial proxy to keep implementations opaque
  - deserialization chooses implementation based on current criteria in effect
  - single, common serial proxy shared by all implementations

Other Behavior Differences

- What's the difference between list3 and list4?

```
List<Integer> list3 = Collections.singletonList(1); // immutable
List<Integer> list4 = List.of(1);
```

- Similarities
  - Mutator methods add(), remove(), set() etc. throw UnsupportedOperationException
- Differences

```
list3.addAll(Collections.emptyList());  // returns false
list4.addAll(Collections.emptyList());  // throws UOE
```

Other Vaguely Collections-Related Java 9 Enhancements

- Arrays.equals
- Arrays.compare
- Arrays.compareUnsigned
- Arrays.mismatch
- Enumeration.asIterator
- Optional.ifPresentOrElse
- Optional.or
- Optional.stream
- Scanner.tokens
- Scanner.findAll
- Matcher.replaceAll
- Matcher.replaceFirst
- Matcher.results
- Collectors.flatMapping
- Collectors.filtering
- Stream.takeWhile
- Stream.dropWhile
- Stream.ofNullable
- Stream.iterate(3-arg)

Summary

- Collections framework is 19 years old, still useful and extensible!
- Primary Java 9 Collection Enhancement: Convenience Factory Methods
  - convenient, space-efficient, immutable
  - promising space & performance improvements from use in JDK 9 itself
  - JEP 269: http://openjdk.java.net/jeps/269
- Try out JDK 9 builds: http://jdk.java.net/9/
- Me:
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