Collections Refueled

Collections Framework Enhancements in Java 9+

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Twenty Years of Java Collections

- JDK 1.0 – 1996
  - "Legacy Collections": Vector, Hashtable
- JDK 1.2 – 1998
  - Collections Framework introduced: Collection, List, Set, Map, ArrayList, HashMap
- Java SE 5.0 – 2004
  - generics introduced, collections generified
  - java.util.concurrent
- Java 8 – 2014
  - lambda, streams; default methods enhanced *all existing* collections

Java 9 – Collections Convenience Factory Methods

- Convenient and Concise
- Space Efficient
- Unmodifiable

Java 9 – Collections Convenience Factory Methods

- Library-only API; no language changes
  - static factory methods for creating new lists, sets, maps
  - gets ~80% of the benefit of language changes at a tiny fraction of the cost
- Why not “collection literals” as in other languages?
  - Java’s only built-in aggregation constructs are arrays and classes
  - higher-level abstractions (collections) are delegated to libraries
  - binding Java language and libraries too tightly would create design discomfort
    - in particular, the language would now depend on collections implementations in java.util

New Java 9 APIs: 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.

List Example

```
// Java 8

    List<String> stringList =
        Collections.unmodifiableList(
            Arrays.asList("a", "b", "c"));



// Java 9

    List<String> stringList = List.of("a", "b", "c");
```

Set Example

```
// Java 8

    Set<String> stringSet =
        Collections.unmodifiableSet(
            new HashSet<>(
                Arrays.asList("a", "b", "c")));


// Java 9

    Set<String> stringSet = Set.of("a", "b", "c");
```

Map Example (<= 10 entries)

```
// Java 8

    Map<String, Integer> stringMap = new HashMap<>();
    stringMap.put("a", 1);
    stringMap.put("b", 2);
    stringMap.put("c", 3);
    stringMap = Collections.unmodifiableMap(stringMap);

// Java 9

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

Map Example (> 10 entries)

```
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)
);
```

The Map.ofEntries() method accepts a varargs argument of Map.Entry instances

Each call to entry() returns a single instance of Map.Entry

Implementation Characteristics

- Unmodifiable
- Nulls Disallowed
- Randomized Iteration Order (Sets and Maps)
- Duplicates Disallowed (Sets and Maps)
- Space Efficient
- Serializable

Unmodifiable

- Collections returned by the new static factory methods are ***unmodifiable***
  - attempts to add, set, or remove throw UnsupportedOperationException
- What good is an unmodifiable collection?
  - collections often initialized from known values, never changed
  - can pass internal collection to client without fear of accidental modification
  - one step towards thread-safety
  - provides opportunities for space efficiency
- These collections themselves are unmodifiable
  - compare Collections.unmodifiableList() etc. wrappers around another collection

Unmodifiable Collections vs. Unmodifiable Wrappers

- What's the difference between list1 and list2?

```
List<Integer> inner = Arrays.asList(1, 2, 3);
List<Integer> list1 = Collections.unmodifiableList(inner);
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 inner
  - inner can be modified, and modifications to it are visible to list1
  - list2 cannot be modified at all

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 (esp. java.util.concurrent) has permitted nulls
  - classic collections like ArrayList, HashMap still allow nulls
- Why not?
  - nulls are a source of NPEs in applications, semantically confusing
  - nulls useful as sentinel values in APIs, e.g., Map.get(), Map.compute()
  - nulls useful as sentinel values for optimizing implementations

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 new 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
- Worried? Use LinkedHashSet / LinkedHashMap

Duplicates Disallowed

- 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

- All implementations are private classes hidden behind static factory
  - static factory method chooses the implementation based on number of elements
- Different data organizations
  - field-based implementations for 0, 1, 2 elements
  - array-based with closed hashing for > 2 elements
  - implementations can be changed compatibly in any JDK release
- Benefits
  - less space overall
  - fewer objects result in improved locality of reference

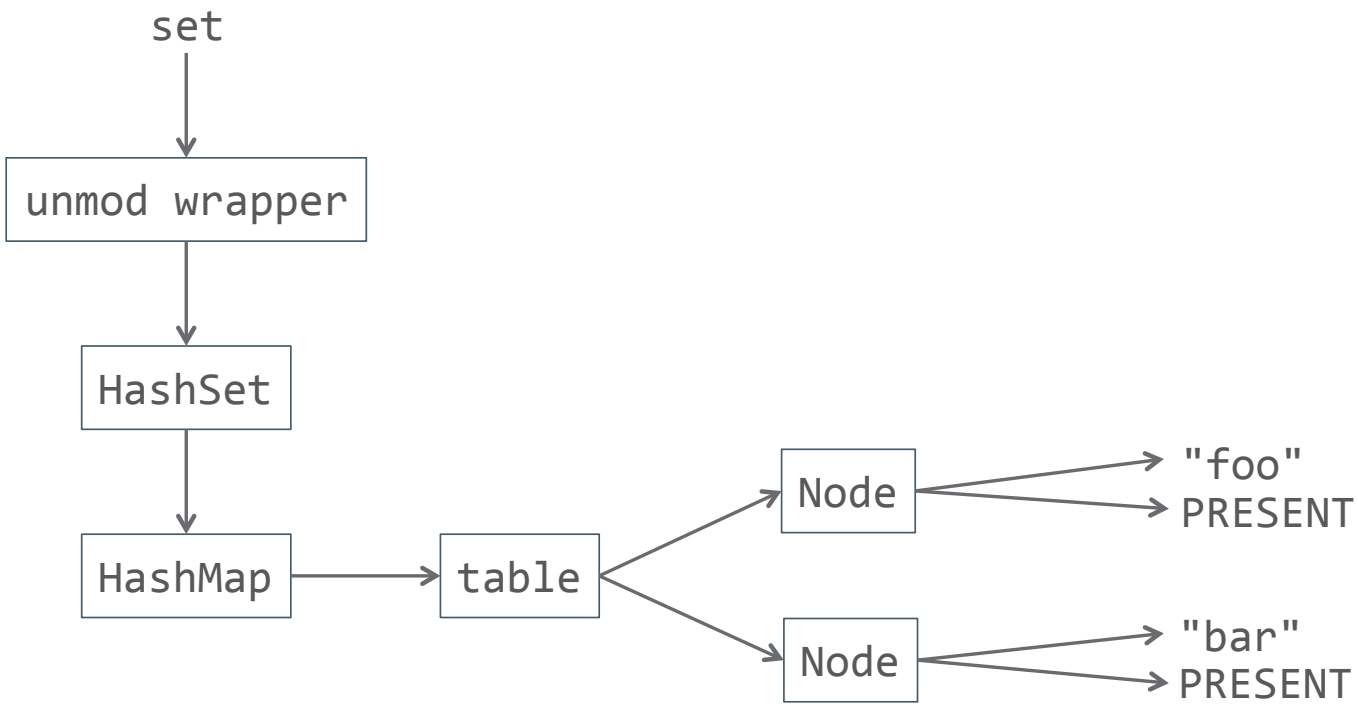
Space Efficiency

- 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

- Object size estimate
  - 12 byte header per object
  - plus 4 bytes per int, float, or reference field
  - (assume 64-bit JVM with compressed OOPS)
- Total collection overhead (not counting contents)
  - 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

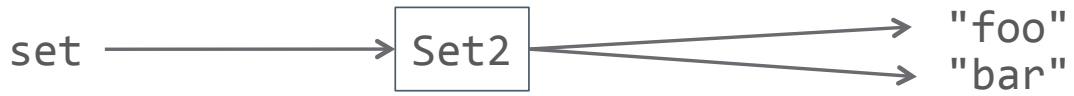
Total 152 bytes to store two object references!

Space Efficiency

- Field-based set implementation

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

- One object, two reference 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



Additional APIs in Java 10

```
// Copy Factories – for making shallow copies
// short-circuits copying if not necessary
// if src is unmodifiable, returns 'this'

List.copyOf(Collection<T> src)
Set.copyOf(Collection<T> src)
Map.copyOf(Map<K,V> src)

// Stream Collectors
// produce same implementations as List.of(), Set.of(), Map.of()

Collectors.toUnmodifiableList()
Collectors.toUnmodifiableSet()
Collectors.toUnmodifiableMap(keyFunc, valFunc)
Collectors.toUnmodifiableMap(keyFunc, valFunc, mergeFunc)
```

allows duplicates

allows duplicates

Summary

- Collections framework is 20 years old, still useful and extensible!
- Java 9 & 10 add Collection Factory Methods & Stream Collectors
  - convenient, concise API
  - space-efficient, unmodifiable implementation
  - space and performance improvements from use inthe JDK itself
- Questions?
  - Twitter: @stuartmarks #CollectionsRefueled