JEP 431: Sequenced Collections

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Summary

Introduce new interfaces to represent collections with a defined encounter order. Each such collection has a well-defined first element, second element, and so forth, up to the last element. It also provides uniform APIs for accessing its first and last elements, and for processing its elements in reverse order.

> "Life can only be understood backwards; but it must be lived forwards."
> — Kierkegaard

Motivation

Java's collections framework lacks a collection type that represents a sequence of elements with a defined encounter order. It also lacks a uniform set of operations that apply across such collections. These gaps have been a repeated source of problems and complaints.

For example, `List` and `Deque` both define an encounter order but their common supertype is `Collection`, which does not. Similarly, `Set` does not define an encounter order, and subtypes such as `HashSet` do not define one, but subtypes such as `SortedSet` and `LinkedHashSet` do. Support for encounter order is thus spread across the type hierarchy, making it difficult to express certain useful concepts in APIs. Neither `Collection` nor `List` can describe a parameter or return value that has an encounter order. `Collection` is too general, relegating such constraints to the prose specification, possibly leading to hard-to-debug errors. `List` is too specific, excluding `SortedSet` and `LinkedHashSet`.

A related problem is that view collections are often forced to downgrade to weaker semantics. Wrapping a `LinkedHashSet` with `Collections::unmodifiableSet` yields a `Set`, discarding the information about encounter order.

Without interfaces to define them, operations related to encounter order are either inconsistent or missing. While many implementations support getting the first or last element, each collection defines its own way, and some are not obvious or are missing entirely:

	First element	Last element
`List`	`list.get(0)`	`list.get(list.size() - 1)`
`Deque`	`deque.getFirst()`	`deque.getLast()`
`SortedSet`	`sortedSet.first()`	`sortedSet.last()`
`LinkedHashSet`	`linkedHashSet.iterator().next()`	*// missing*

Some of these are unnecessarily cumbersome, such as getting the last element of a `List`. Some are not even possible without heroics: The only way to get the last element of a `LinkedHashSet` is to iterate the entire set.

Similarly, iterating the elements of a collection from first to last is straightforward and consistent, but iterating in reverse order is neither. All of these collections can be iterated forward with an `Iterator`, the enhanced for loop, a `stream()`, or `toArray()`. Iterating in reverse is different in every case. `NavigableSet` provides the `descendingSet()` view for reverse iteration:

```
for (var e : navSet.descendingSet())
    process(e);
```

Deque does so with a reverse `Iterator`:

```
for (var it = deque.descendingIterator(); it.hasNext();) {
    var e = it.next();
    process(e);
}
```

`List` does so but with `ListIterator`:

```
for (var it = list.listIterator(list.size()); it.hasPrevious();) {
    var e = it.previous();
    process(e);
}
```

`LinkedHashSet`, finally, provides no support for reverse iteration. The only practical way to process the elements of a `LinkedHashSet` in reverse order is to copy its elements into another collection.

Similarly, processing a collection's elements using streams is a powerful and effective alternative to processing elements using loops, but obtaining a stream in reverse order can be difficult. Of the various collections that define encounter order, the only one that supports this conveniently is `NavigableSet`:

```
navSet.descendingSet().stream()
```

The others require either copying the elements to another collection or creating a stream from a customized `Spliterator` that reverses iteration.

This is an unfortunate state of affairs. The concept of a collection with defined encounter order exists in multiple places in the collections framework, but there is no single type that represents it. As a result, some operations on such collections are inconsistent or missing, and processing elements in reverse order ranges from inconvenient to impossible. We should fill these gaps.

Description

We define new interfaces for sequenced collections, sequenced sets, and sequenced maps, and then retrofit them into the existing collections type hierarchy. All of the new methods declared in these interfaces have default implementations.

Sequenced collections

A *sequenced collection* is a `Collection` whose elements have a defined encounter order. (The word "sequenced" as used here is the past participle of the verb *to sequence*, meaning "to arrange elements in a particular order.") A sequenced collection has first and last elements, and the elements between them have successors and predecessors. A sequenced collection supports common operations at either end, and it supports processing the elements from first to last and from last to first (i.e., forward and reverse).

```
interface SequencedCollection<E> extends Collection<E> {
    // new method
    SequencedCollection<E> reversed();
    // methods promoted from Deque
    void addFirst(E);
    void addLast(E);
    E getFirst();
    E getLast();
    E removeFirst();
    E removeLast();
}
```

The new `reversed()` method provides a reverse-ordered view of the original collection. Any modifications to the original collection are visible in the view. If permitted, modifications to the view write through to the original collection.

The reverse-ordered view enables all the different sequenced types to process elements in both directions, using all the usual iteration mechanisms: Enhanced for loops, explicit `iterator()` loops, `forEach()`, `stream()`, `parallelStream()`, and `toArray()`.

For example, obtaining a reverse-ordered stream from a `LinkedHashSet` was previously quite difficult; now it is simply

```
linkedHashSet.reversed().stream()
```

(The `reversed()` method is essentially a renamed `NavigableSet::descendingSet`, promoted to `SequencedCollection`.)

The following methods of `SequencedCollection` are promoted from `Deque`. They support adding, getting, and removing elements at both ends:

- `void addFirst(E)`
- `void addLast(E)`
- `E getFirst()`
- `E getLast()`
- `E removeFirst()`
- `E removeLast()`

The `add*(E)` and `remove*()` methods are optional, primarily to support the case of unmodifiable collections. The `get*()` and `remove*()` methods throw `NoSuchElementException` if the collection is empty.

There are no definitions of `equals()` and `hashCode()` in `SequencedCollection` because its sub-interfaces have conflicting definitions.

Sequenced sets

A *sequenced set* is a `Set` that is a `SequencedCollection` that contains no duplicate elements.

```
interface SequencedSet<E> extends Set<E>, SequencedCollection<E> {
    SequencedSet<E> reversed();    // covariant override
}
```

Collections such as `SortedSet`, which position elements by relative comparison, cannot support explicit-positioning operations such as `addFirst(E)` and `addLast(E)` methods declared in the `SequencedCollection` superinterface. Thus, these methods can throw `UnsupportedOperationException`.

The `addFirst(E)` and `addLast(E)` methods of `SequencedSet` have special-case semantics for collections such as `LinkedHashSet`: If the element is already present in the set then it is moved to the appropriate position. This remedies a long-standing deficiency in `LinkedHashSet`, namely the inability to reposition elements.

Sequenced maps

A *sequenced map* is a `Map` whose entries have a defined encounter order.

```
interface SequencedMap<K,V> extends Map<K,V> {
    // new methods
    SequencedMap<K,V> reversed();
    SequencedSet<K> sequencedKeySet();
    SequencedCollection<V> sequencedValues();
    SequencedSet<Entry<K,V>> sequencedEntrySet();
    V putFirst(K, V);
    V putLast(K, V);
    // methods promoted from NavigableMap
    Entry<K, V> firstEntry();
    Entry<K, V> lastEntry();
    Entry<K, V> pollFirstEntry();
    Entry<K, V> pollLastEntry();
}
```

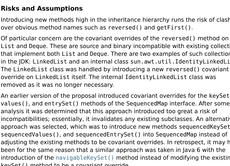
The new `put*(K, V)` methods have special-case semantics, similar to the corresponding `add*(E)` methods of `SequencedSet`: For maps such as `LinkedHashMap`, they have the additional effect of repositioning the entry if it is already present in the map. For maps such as `SortedMap`, these methods throw `UnsupportedOperationException`.

The following methods of `SequencedMap` are promoted from `NavigableMap`. They support getting and removing entries at both ends:

- `Entry<K, V> firstEntry()`
- `Entry<K, V> lastEntry()`
- `Entry<K, V> pollFirstEntry()`
- `Entry<K, V> pollLastEntry()`

Retrofitting

The three new interfaces defined above fit neatly into the existing collections type hierarchy (click to enlarge):



In detail, we make the following adjustments to retrofit existing classes and interfaces:

- `List` now has `SequencedCollection` as its immediate superinterface.
- `Deque` now has `SequencedCollection` as its immediate superinterface.
- `LinkedHashSet` additionally implements `SequencedSet`.
- `SortedSet` now has `SequencedSet` as its immediate superinterface.
- `LinkedHashMap` additionally implements `SequencedMap`, and
- `SortedMap` now has `SequencedMap` as its immediate superinterface.

We define covariant overrides for the `reversed()` method in the appropriate places. For example, `List::reversed` is overridden to return a value of type `List` rather than a value of type `SequencedCollection`.

We also add new methods to the `Collections` utility class to create unmodifiable wrappers for the three new types:

- `Collections.unmodifiableSequencedCollection(sequencedCollection)`
- `Collections.unmodifiableSequencedSet(sequencedSet)`
- `Collections.unmodifiableSequencedMap(sequencedMap)`

Alternatives

Types

An alternative to adding new types would be to repurpose the `List` interface as a general sequenced collection type. Indeed `List` is sequenced, but it also supports element access by integer index. Many sequenced data structures do not naturally support indexing and would thus be required to support it iteratively. This would result in indexed access having O(n) performance instead of the expected O(1), perpetuating the mistake of `LinkedList`.

Deque seems promising as a general sequence type, since it already supports the right set of operations. However, it is cluttered with other operations, including a family of null-returning operations (offer, peek, and poll), stack operations (push and pop), and operations inherited from Queue. These operations are sensible for a queue but less so for other collections. If Deque were repurposed as a general sequence type then `List` would also be a Queue and would support stack operations, resulting in a cluttered and confusing API.

Naming

The term *sequence*, which we have chosen here, implies elements that are arranged in order. It is commonly used across various platforms to represent collections with semantics similar to those described above.

The term *ordered* is not quite specific enough. We require iteration in both directions, and operations at both ends. An ordered collection such as a Queue is a notable outlier: It is ordered, but it is also decidedly asymmetric.

The term *reversible*, used in an earlier version of this proposal, does not immediately evoke the concept of having two ends. Perhaps a bigger issue is that the `Map` variant would be named `ReversibleMap`, which misleadingly implies that it supports lookup by key and by value (sometimes called a `BiMap` or `BidiMap`).

`Add, put, and UnsupportedOperationException`

As described above, explicit-positioning APIs such as `SortedSet::addFirst` and `SortedMap::putLast` throw `UnsupportedOperationException` because the sequence of their elements is determined by relative comparison. The asymmetry of having some collections not implement all of the `SequencedCollection` operations may seem unpleasant. It is nonetheless valuable because it brings `SortedSet` and `SortedMap` into the sequenced collection family, allowing them to be used more broadly than otherwise. This asymmetry is, also, consistent with prior design decisions in the collections framework. For example, the `Map::keySet` method returns a `Set`, even though the implementation returned does not support addition.

Alternatively, the addition operations could be kept separate by rearranging the interfaces along structural lines. That would result in new interface types with very thin semantics (e.g., `AddableCollection`) that are not useful in practice and that clutter up the type hierarchy.

History

This proposal is an incremental evolution of our 2021 `ReversibleCollections` proposal. The major changes from that proposal are renaming, the addition of the `SequencedMap` interface, and the addition of unmodifiable wrapper methods.

The `ReversibleCollection` proposal was in turn based on Tagir Valeev's 2020 `OrderedMap/OrderedSet` proposal. Several fundamental concepts from that proposal are still present, although there are many differences in detail.

Over the years we have received many requests and proposals in the vein of combining a `List` with a `Set` or `Map`. The recurring themes are a `List` that contains unique elements, or a `Set` or `Map` that maintains ordering. These requests include 4152834, 4245809, 4264420, 4268146, 6447049, and 8037382.

Some of these requests were partially addressed with the introduction of `LinkedHashSet` and `LinkedHashMap` in Java 1.4. While those classes do satisfy some use cases, their introduction left gaps in the abstractions and operations provided by the collections framework, as described above.

Testing

We will add a comprehensive set of tests to the JDK's regression test suite.

Risks and Assumptions

Introducing new methods high in the inheritance hierarchy runs the risk of clashes over obvious method names such as `reversed()` and `getFirst()`.

Of particular concern are the covariant overrides of the `reversed()` method on `List` and `Deque`. These are source and binary incompatible with existing collections that implement both `List` and `Deque`. There are two examples of such collections in the JDK: `LinkedList` and an internal class `sun.awt.util.IdentityLinkedList`. The `LinkedList` class was handled by introducing a new `reversed()` covariant override on `LinkedList` itself. The internal `IdentityLinkedList` class was removed as it was no longer necessary.

An earlier version of the proposal introduced covariant overrides for the `keySet()`, `values()`, and `entrySet()` methods of the `SequencedMap` interface. After some analysis it was determined that this approach introduced too great a risk of incompatibilities; essentially, it invalidates any existing subclasses. An alternative approach was selected, which was to introduce new methods `sequencedKeySet()`, `sequencedValues()`, and `sequencedEntrySet()` into `SequencedMap` instead of adjusting the existing methods to be covariant overrides. In retrospect, it may have been for the same reason that a similar approach was taken in Java 6 with the introduction of the `navigableKeySet()` method instead of modifying the existing `keySet()` method to be a covariant override.

See the report attached to the CSR, JDK-8266572, for a full analysis of the incompatibility risk.