Java 8 Parallel Stream Internals

(Part 5)

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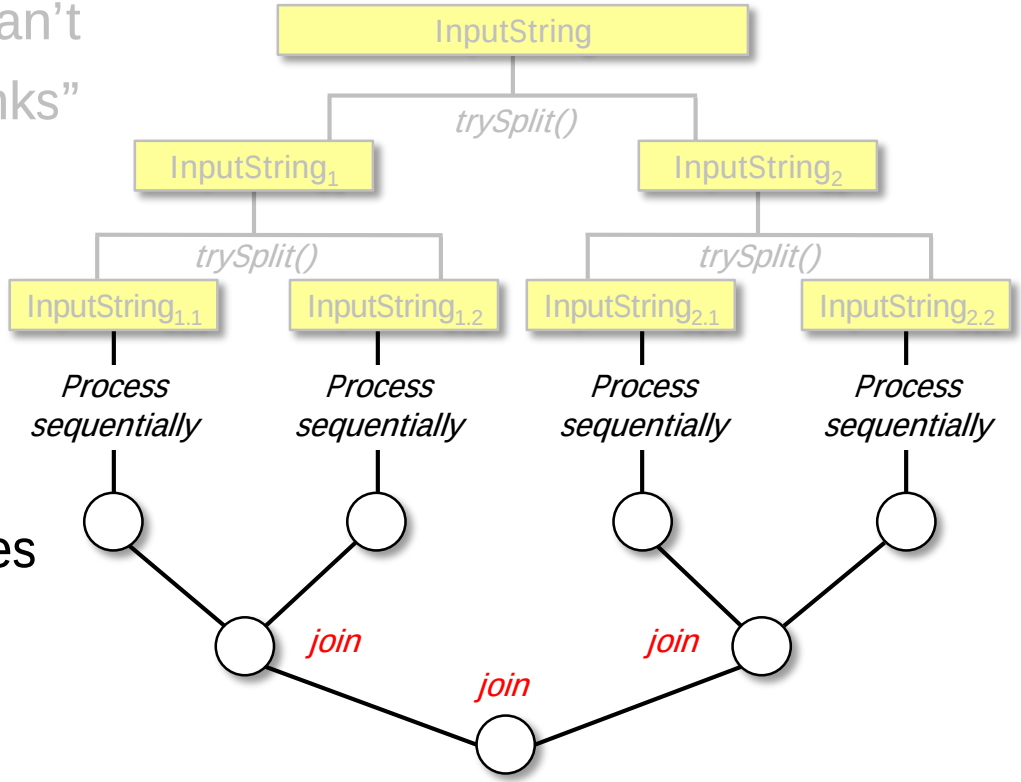
Learning Objectives in this Part of the Lesson

- Understand parallel stream internals, e.g.
  - Know what can change & what can't
  - Partition a data source into "chunks"
  - Process chunks in parallel
  - Configure the Java 8 parallel stream common fork-join pool
  - Avoid pool starvation & improve performance w/ManagedBlocker
  - Perform a reduction that combines partial results into a single result

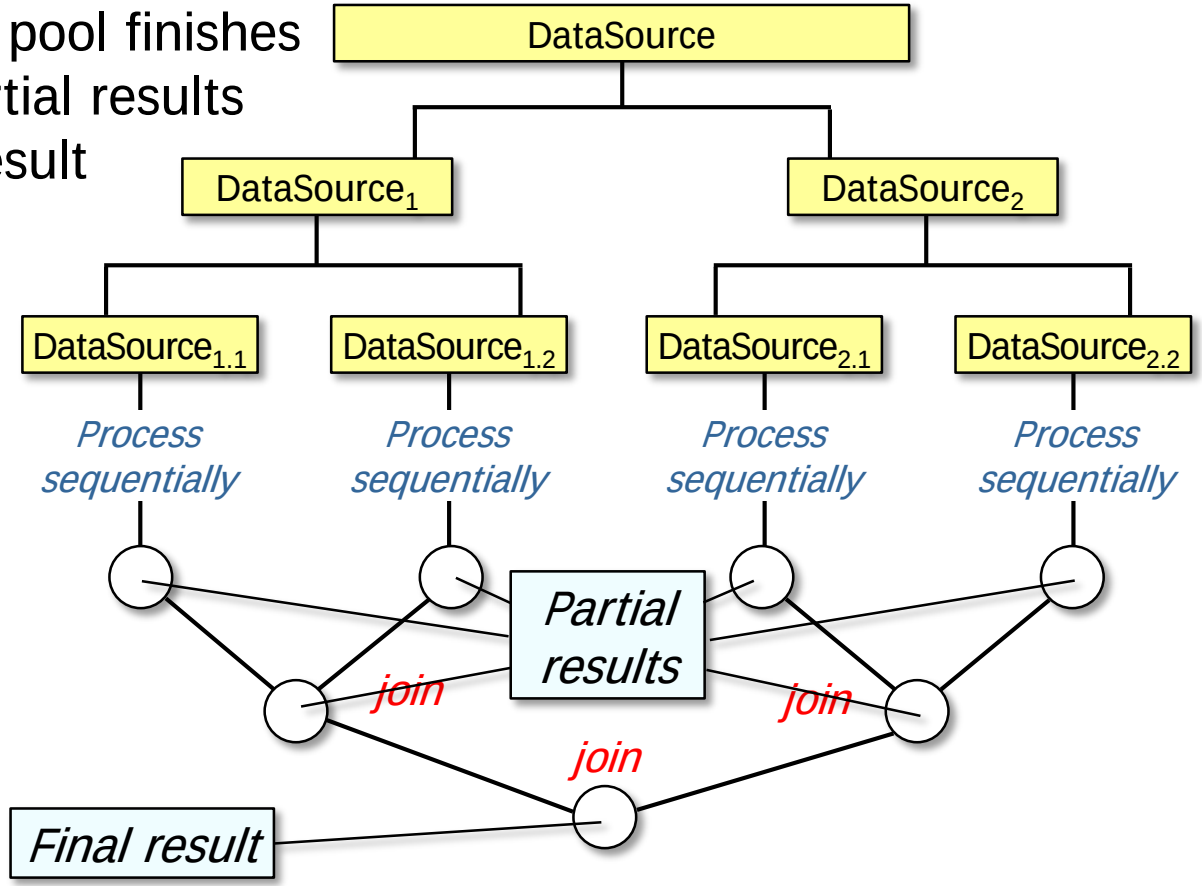


See www.ibm.com/developerworks/library/j-java-streams-3-brian-goetz

Combining Results in a Parallel Stream

Combining Results in a Parallel Stream

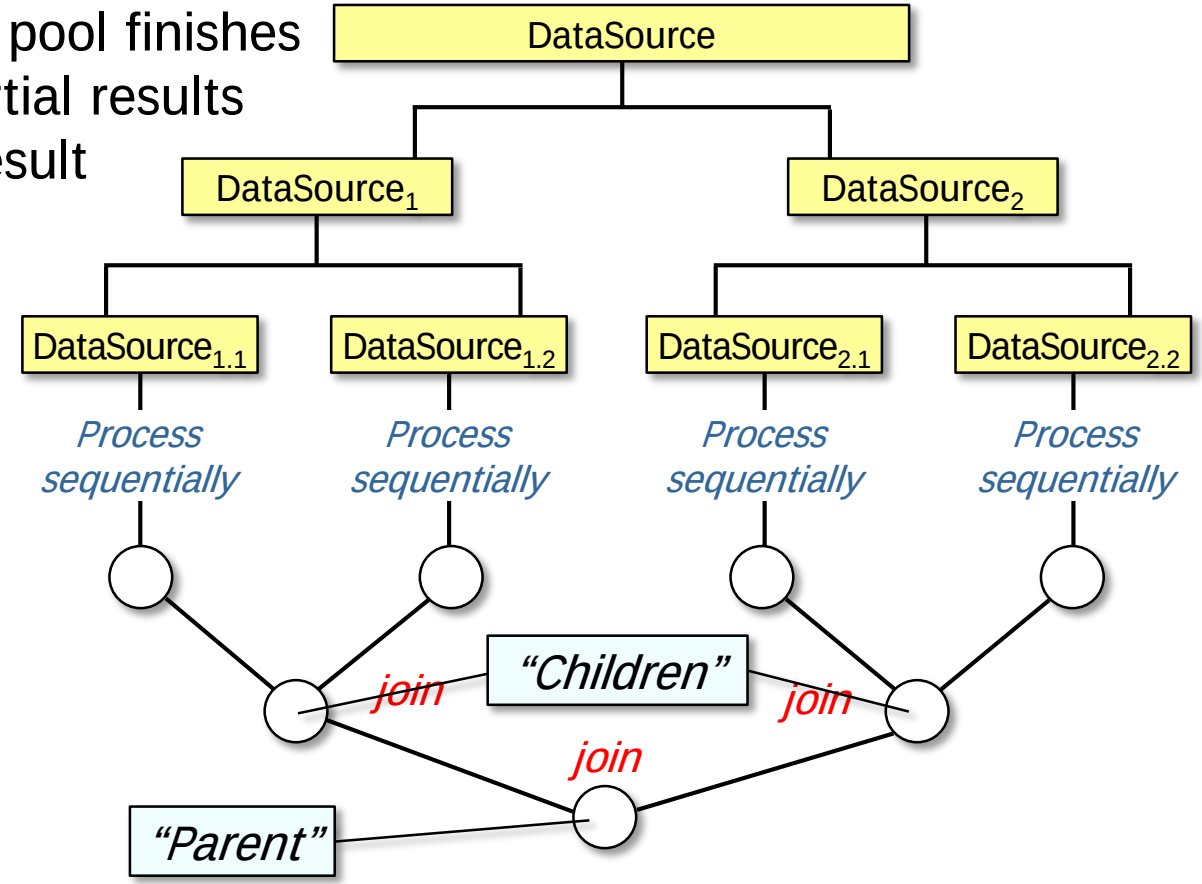
- After the common fork-join pool finishes processing chunks their partial results are combined into a final result



This discussion assumes a non-concurrent collector (more discussions follow)

Combining Results in a Parallel Stream

- After the common fork-join pool finishes processing chunks their partial results are combined into a final result
  - join() occurs in a single thread at each level
    - i.e., the “parent”



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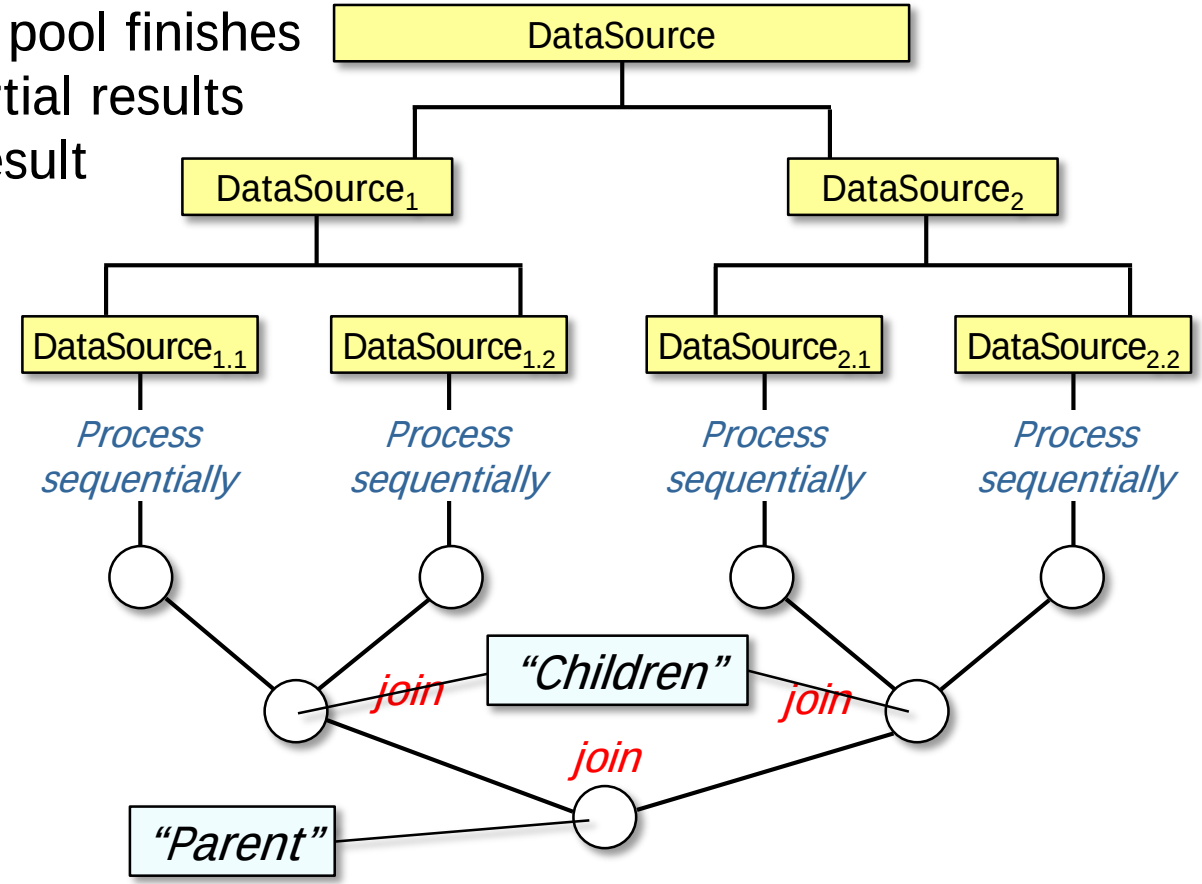
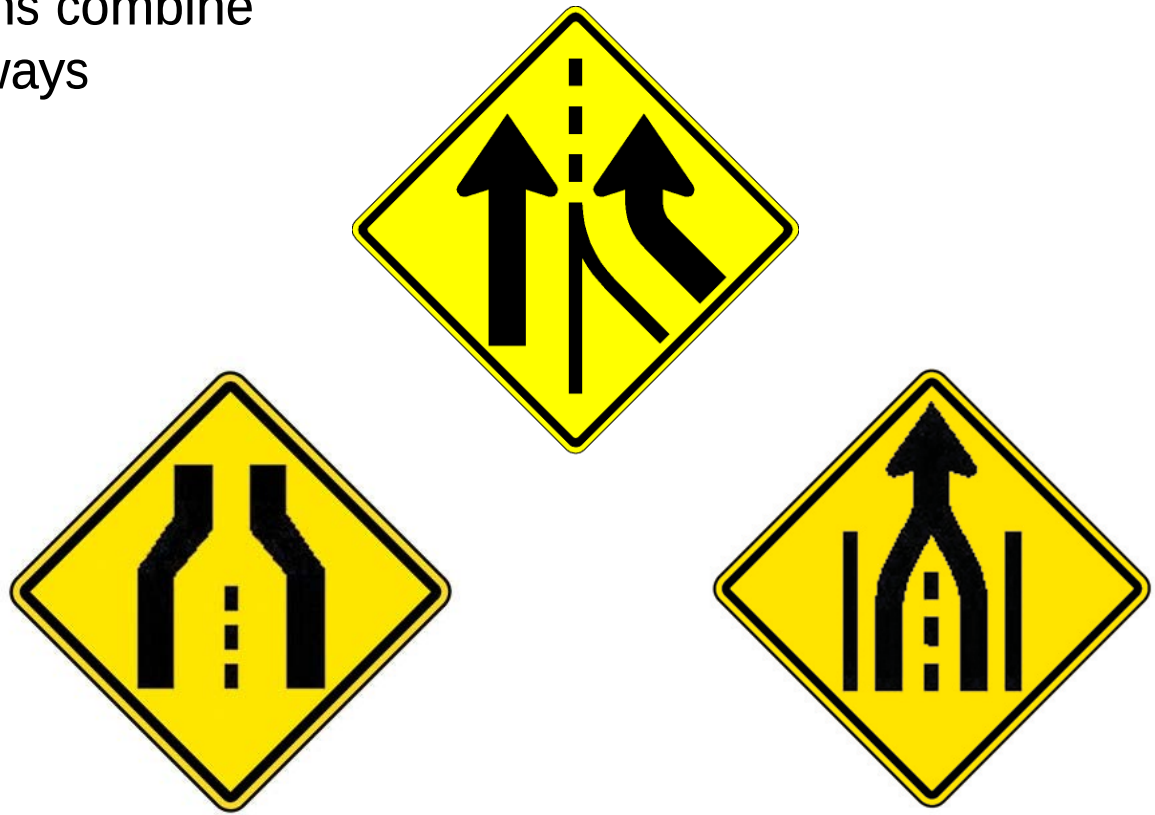


As a result, there’s typically no need for synchronizers during the joining

Combining Results in a Parallel Stream

- Different terminal operations combine partial results in different ways



Understanding these differences is particularly important for parallel streams

Combining Results in a Parallel Stream

- Different terminal operations combine partial results in different ways, e.g.
  - reduce() creates a new immutable value

See docs.oracle.com/javase/tutorial/essential/concurrency/immutable.html

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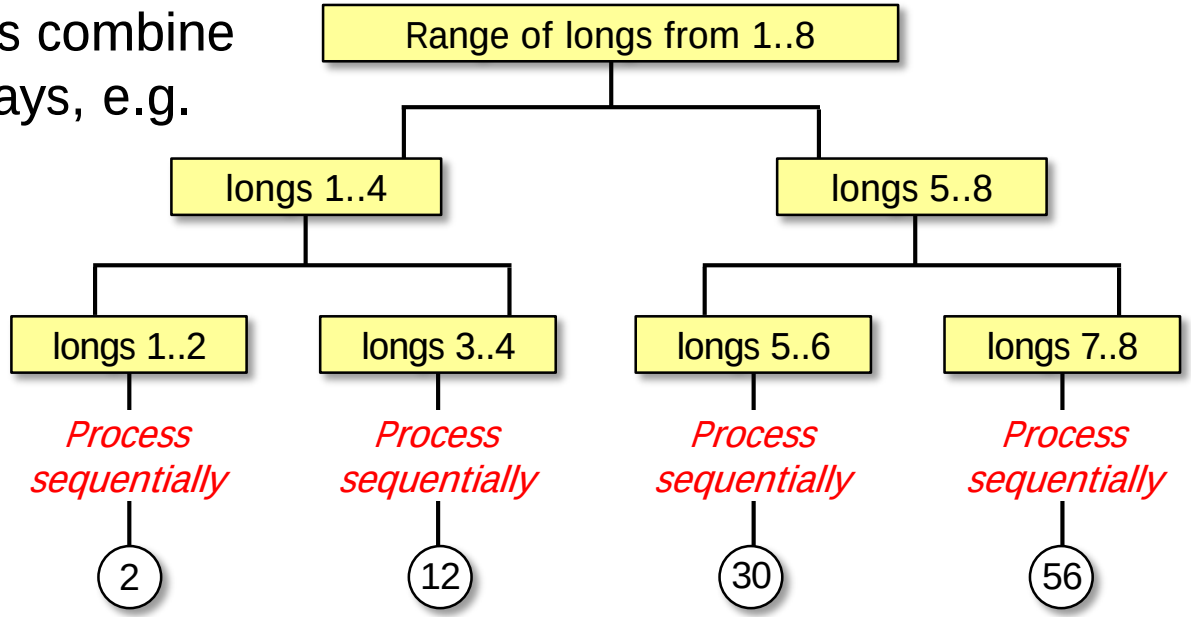


```
long factorial(long n) {
  return LongStream
    .rangeClosed(1, n)
    .parallel()
    .reduce(1, (a, b) -> a * b,
            (a, b) -> a * b);
}
```

See github.com/douglascraigschmidt/LiveLessons/tree/master/Java8/ex16

Combining Results in a Parallel Stream

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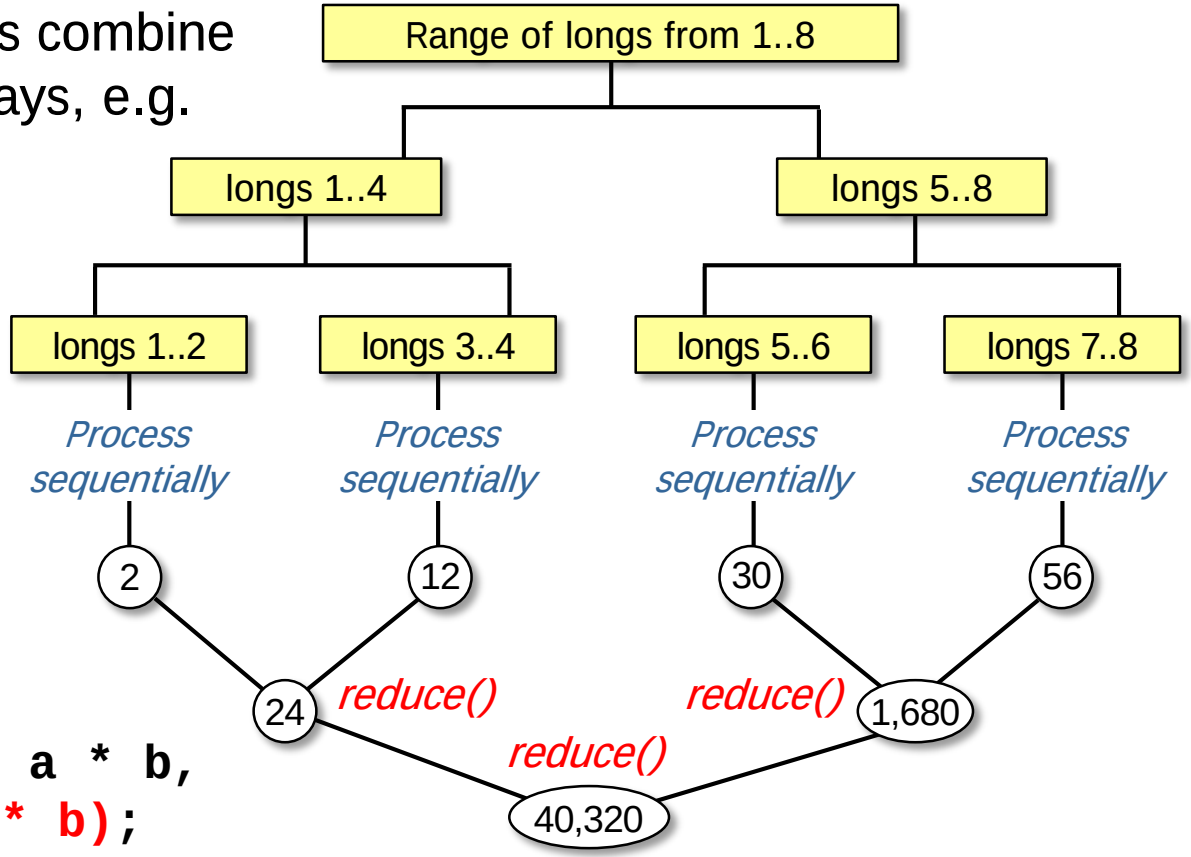


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}
```

reduce() combines two immutable values (e.g., long or Long) & produces a new one

Combining Results in a Parallel Stream

- Different terminal operations combine partial results in different ways, e.g.
  - reduce() creates a new immutable value
  - collect() mutates an existing value

See greenteapress.com/thinkapjava/html/thinkjava011.html

Combining Results in a Parallel Stream

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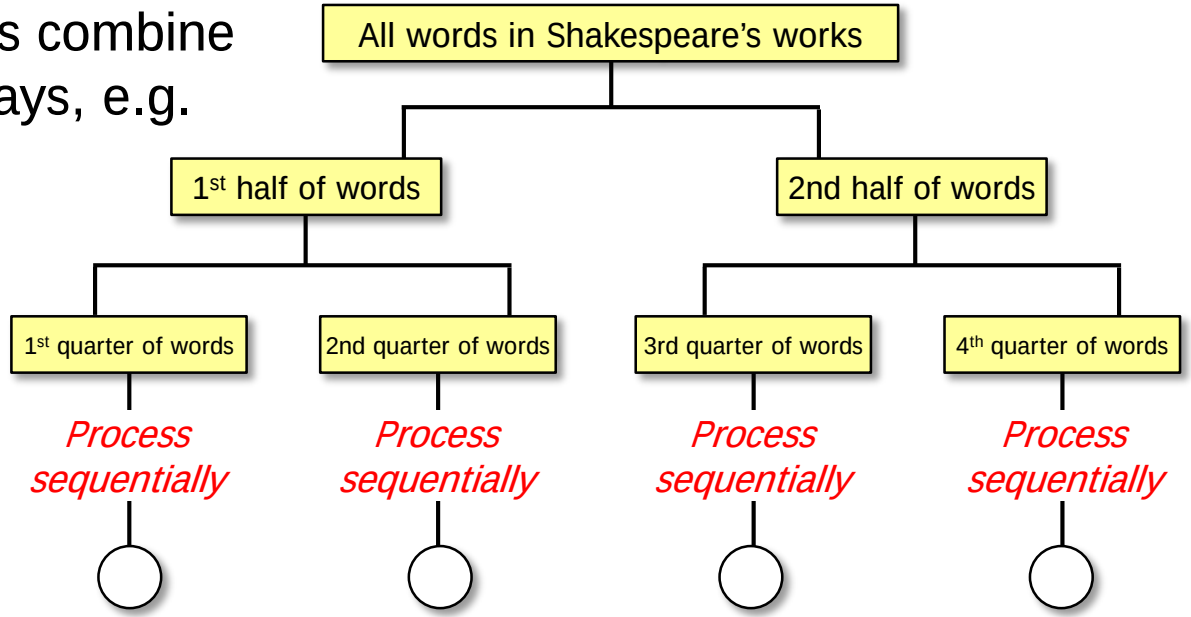


```
List<CharSequence>
      uniqueWords =
  getInput(sSHAKESPEARE),
           "\\s+")
  .parallelStream()
  ...
  .collect(toCollection(TreeSet::new));
```

See github.com/douglascraigschmidt/LiveLessons/tree/master/Java8/ex14

Combining Results in a Parallel Stream

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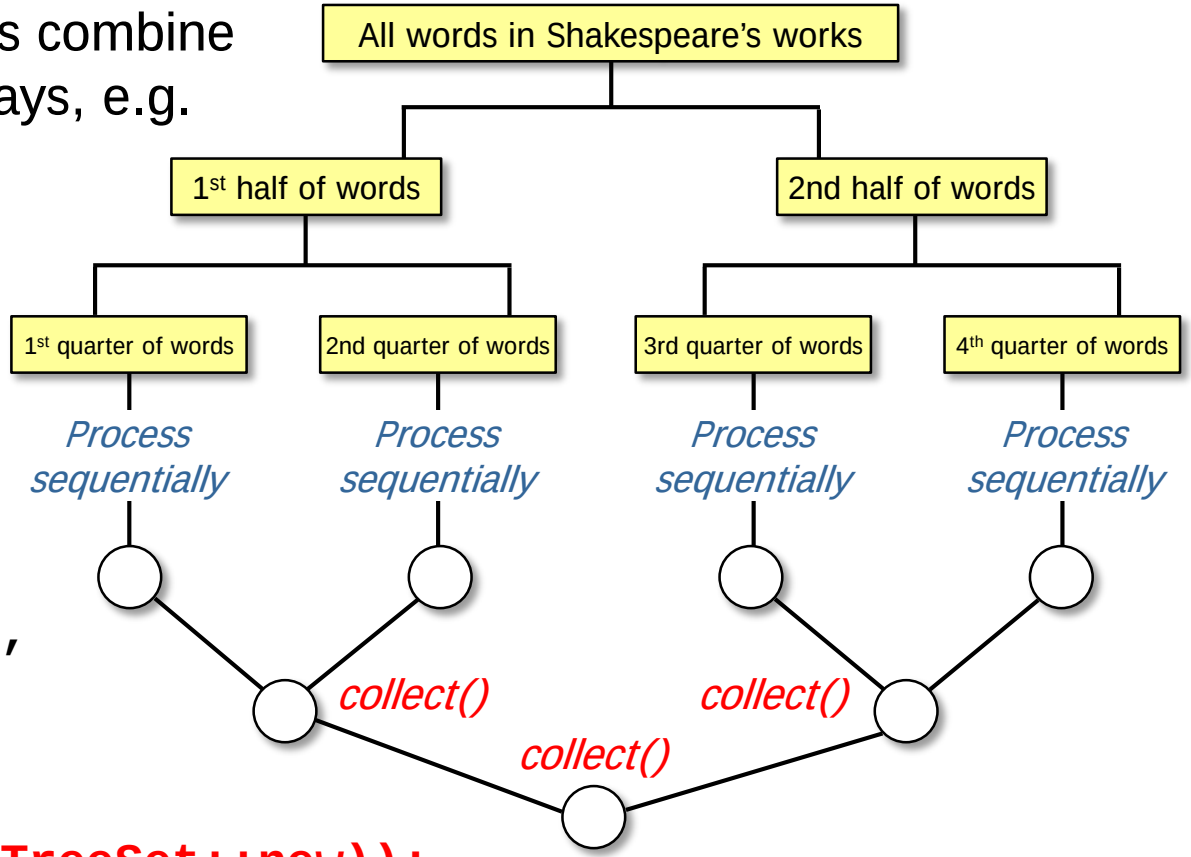


```
List<CharSequence>
      uniqueWords =
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  .parallelStream()
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```

collect() mutates a container to accumulate the result it's producing

Combining Results in a Parallel Stream

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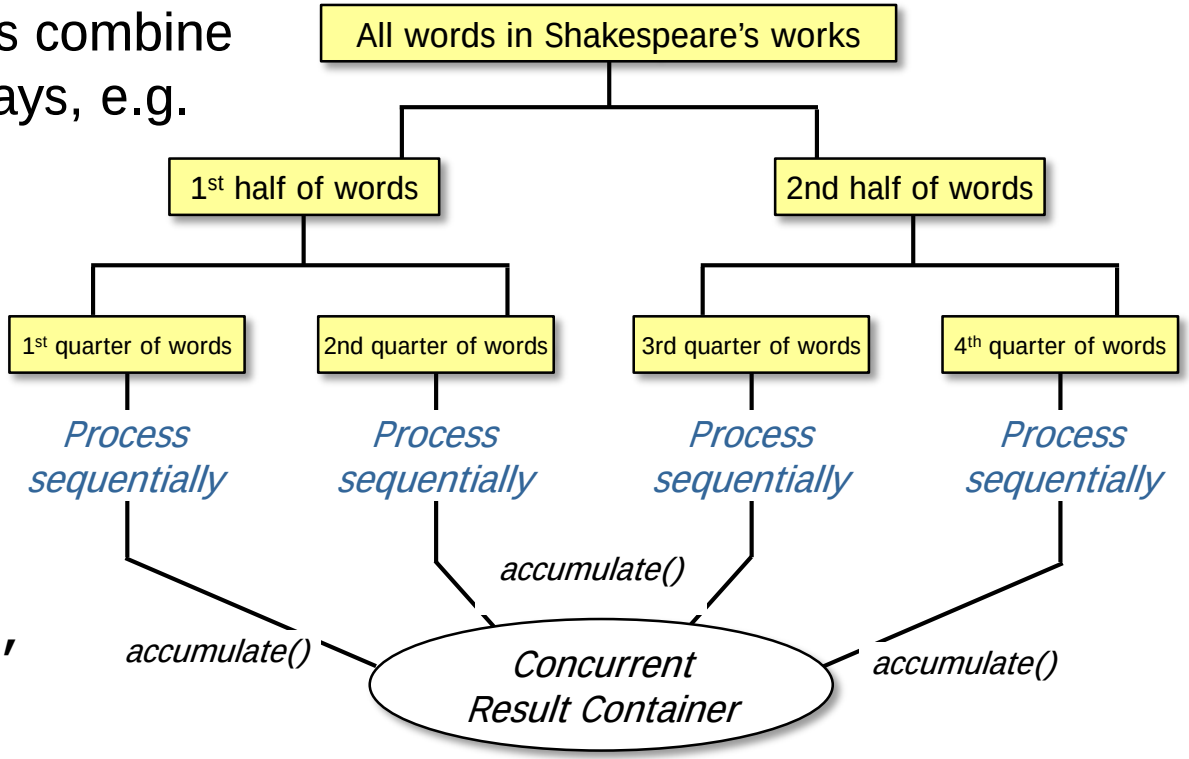
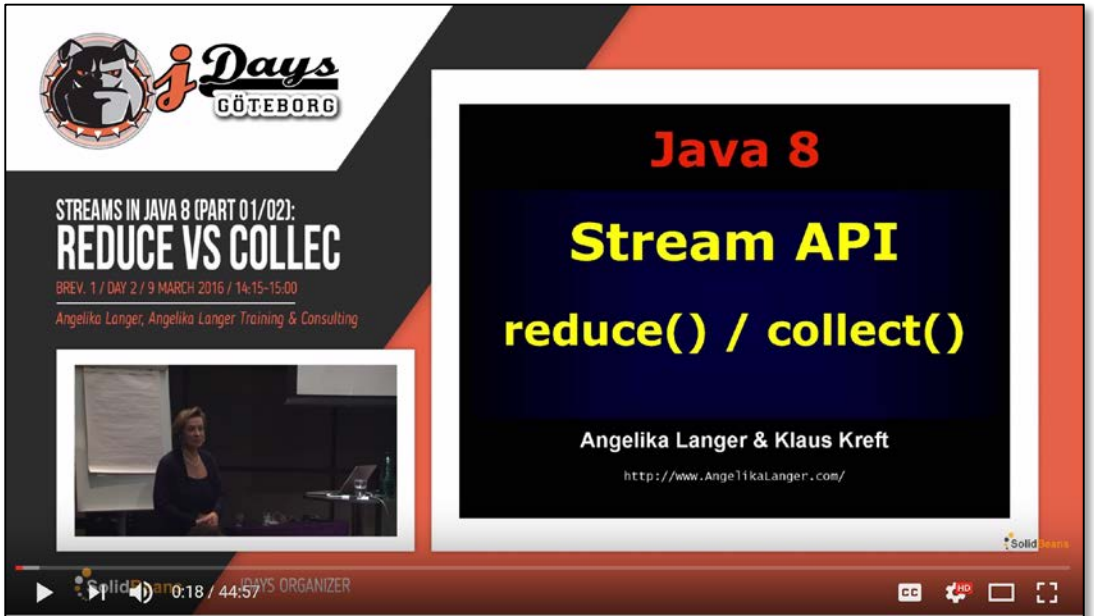



```
List<CharSequence>
      uniqueWords =
  getInput(sSHAKESPEARE),
           "\\s+")
  .parallelStream()
  ...
  .collect(ConcurrentHashSetCollector.toSet());
```

Concurrent collectors are different than non-concurrent collectors (covered later)

Combining Results in a Parallel Stream

- More discussion about reduce() vs. collect() appears online



See www.youtube.com/watch?v=oWlWEKNM5Aw

Combining Results in a Parallel Stream

- More discussion about reduce() vs. collect() appears online, e.g.
  - Always test w/a parallel stream to detect mistakes wrt mutable vs. immutable reductions

```
void buggyStreamReduce
        (boolean parallel) {
  ...
  Stream<String> wordStream =
    allWords.stream();

  if (parallel)
    wordStream.parallel();

  String words = wordStream
    .reduce(new StringBuilder(),
            StringBuilder::append,
            StringBuilder::append)
    .toString();
```

See github.com/douglascraigschmidt/LiveLessons/tree/master/Java8/ex17

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This code fails when parallel() is used since reduce() expects to do an "immutable" reduction

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There are race conditions here since there's just one shared StringBuilder, which is not properly thread-safe..

Combining Results in a Parallel Stream

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A stream can be dynamically switched to "parallel" mode!

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Combining Results in a Parallel Stream

- More discussion about reduce() vs. collect() appears online, e.g.
  - Always test w/a parallel stream to detect mistakes wrt mutable vs. immutable reductions
  - Beware of issues related to association & identity

```
void testDifferenceReduce(...) {
  long difference = LongStream
    .rangeClosed(1, 100)
    .parallel()
    .reduce(0L,
            (x, y) -> x - y);
}

void testSum(long identity, ...) {
  long sum = LongStream
    .rangeClosed(1, 100)
    .reduce(identity,
     // Could use (x, y) -> x + y
           Math::addExact);
```

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This code fails for a parallel stream since subtraction is not associative

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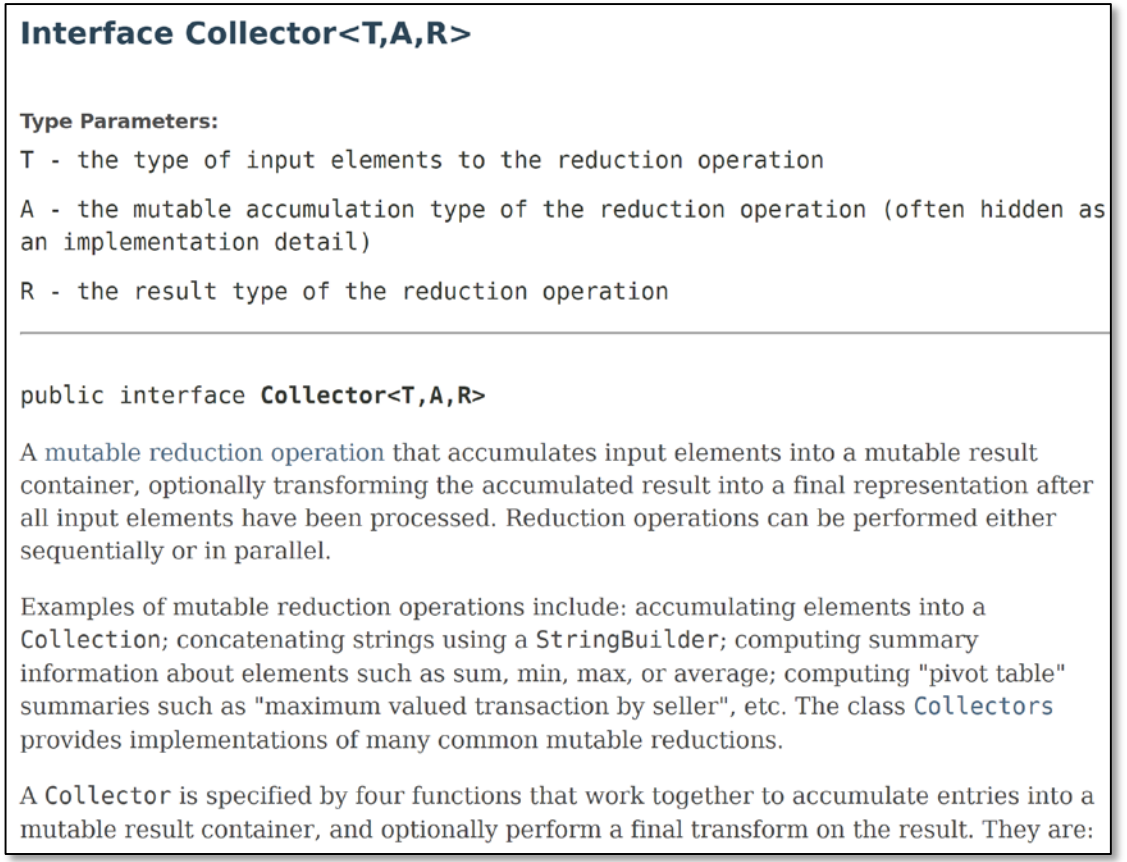
This code fails if identity is not 0L

The “identity” of an OP is defined as “identity OP value == value”

Implementing Concurrent & Non-Concurrent Collectors

Implementing Concurrent & Non-Concurrent Collectors

- Collector defines an interface whose implementations can accumulate input elements in a mutable result container



Interface Collector<T,A,R>

Type Parameters:

`T` - the type of input elements to the reduction operation

`A` - the mutable accumulation type of the reduction operation (often hidden as an implementation detail)

`R` - the result type of the reduction operation

`public interface` **`Collector<T,A,R>`**

A mutable reduction operation that accumulates input elements into a mutable result container, optionally transforming the accumulated result into a final representation after all input elements have been processed. Reduction operations can be performed either sequentially or in parallel.

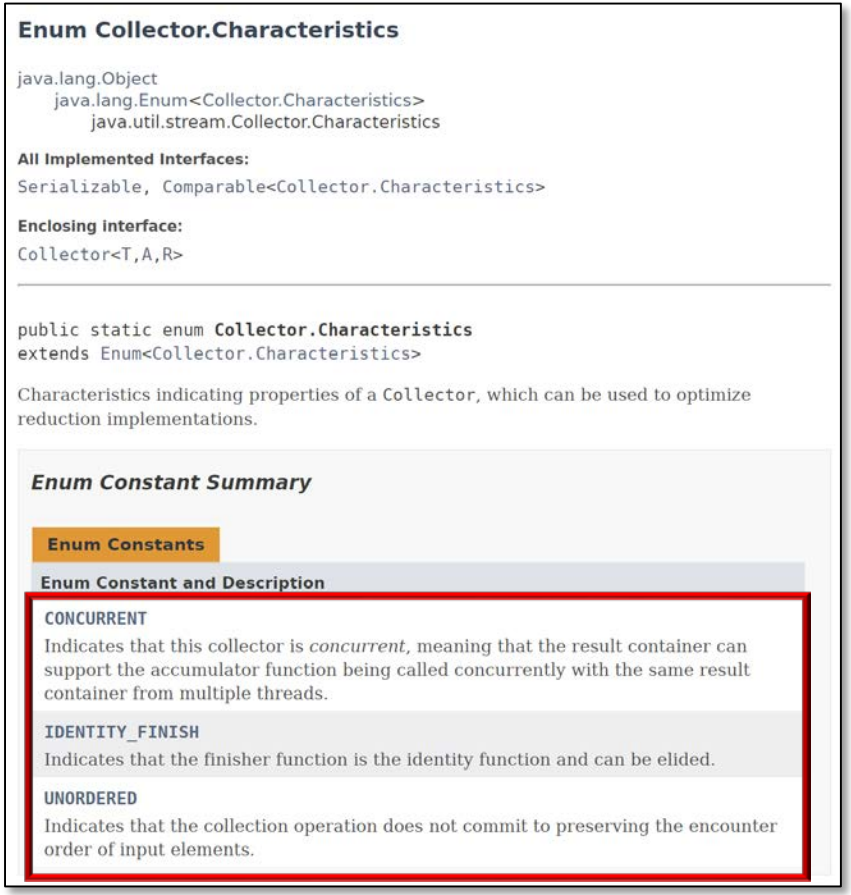
Examples of mutable reduction operations include: accumulating elements into a `Collection`; concatenating strings using a `StringBuilder`; computing summary information about elements such as sum, min, max, or average; computing "pivot table" summaries such as "maximum valued transaction by seller", etc. The class `Collectors` provides implementations of many common mutable reductions.

A `Collector` is specified by four functions that work together to accumulate entries into a mutable result container, and optionally perform a final transform on the result. They are:

See docs.oracle.com/javase/8/docs/api/java/util/stream/Collector.html

Implementing Concurrent & Non-Concurrent Collectors

- Collector implementations can either be non-concurrent or concurrent based on their characteristics



Enum Collector.Characteristics

java.lang.Object
  java.lang.Enum<Collector.Characteristics>
    java.util.stream.Collector.Characteristics

All Implemented Interfaces:

`Serializable, Comparable<Collector.Characteristics>`

Enclosing interface:

`Collector<T,A,R>`

```
public static enum Collector.Characteristics
extends Enum<Collector.Characteristics>
```

Characteristics indicating properties of a `Collector`, which can be used to optimize reduction implementations.

Enum Constant Summary

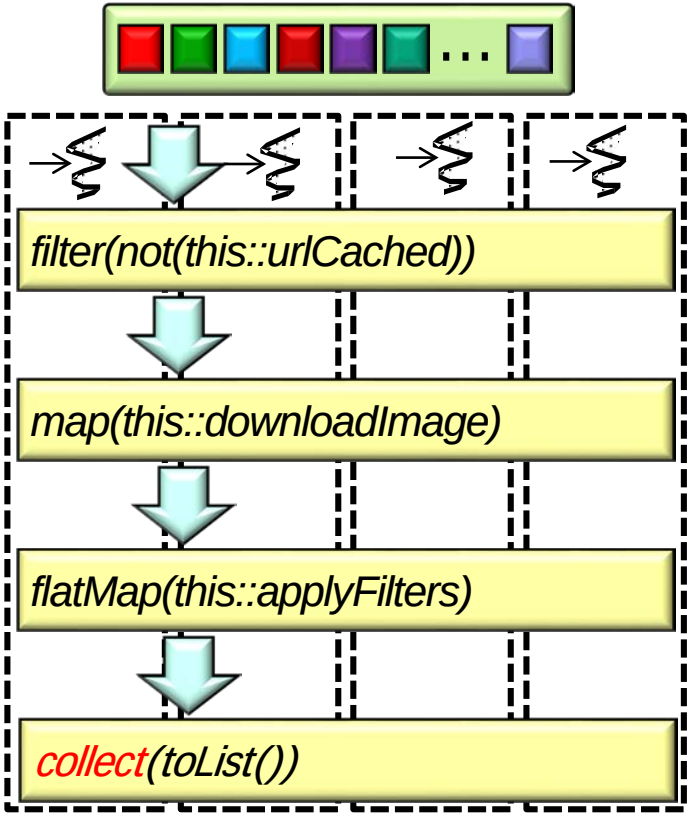
Enum Constants

Enum Constant and Description
`CONCURRENT` Indicates that this collector is *concurrent*, meaning that the result container can support the accumulator function being called concurrently with the same result container from multiple threads.
`IDENTITY_FINISH` Indicates that the finisher function is the identity function and can be elided.
`UNORDERED` Indicates that the collection operation does not commit to preserving the encounter order of input elements.

See docs.oracle.com/javase/8/docs/api/java/util/stream/Collector.Characteristics.html

Implementing Concurrent & Non-Concurrent Collectors

- Collector implementations can either be non-concurrent or concurrent based on their characteristics
  - This distinction is only relevant for *parallel* streams



See *"Overview of Java 8 Streams (Part 4)"* for non-concurrent collector implementation

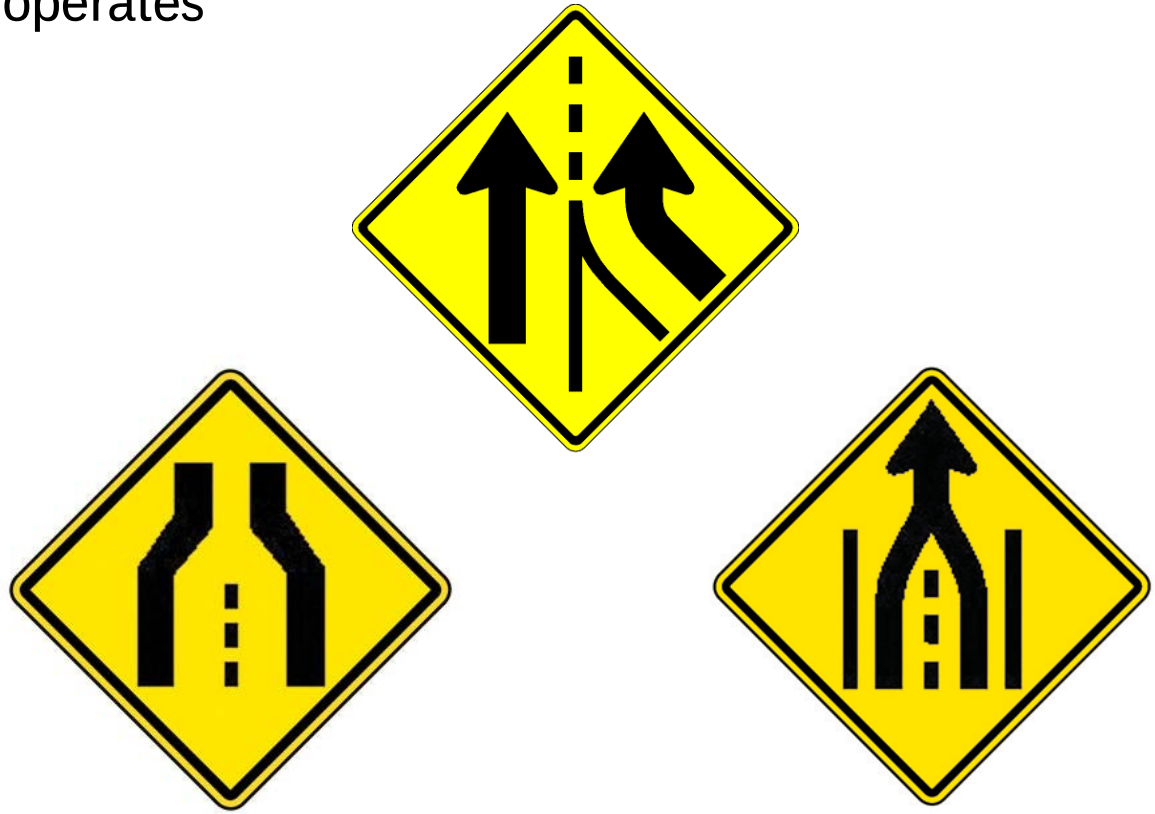
Implementing Concurrent & Non-Concurrent Collectors

- Collector implementations can either be non-concurrent or concurrent based on their characteristics
  - This distinction is only relevant for *parallel* streams
  - A non-concurrent collector can be used for either a sequential stream or a parallel stream!

We'll just focus on parallel streams in the subsequent discussion

Implementing Concurrent & Non-Concurrent Collectors

- A non-concurrent collector operates by merging sub-results



See stackoverflow.com/questions/22350288/parallel-streams-collectors-and-thread-safety

Implementing Concurrent & Non-Concurrent Collectors

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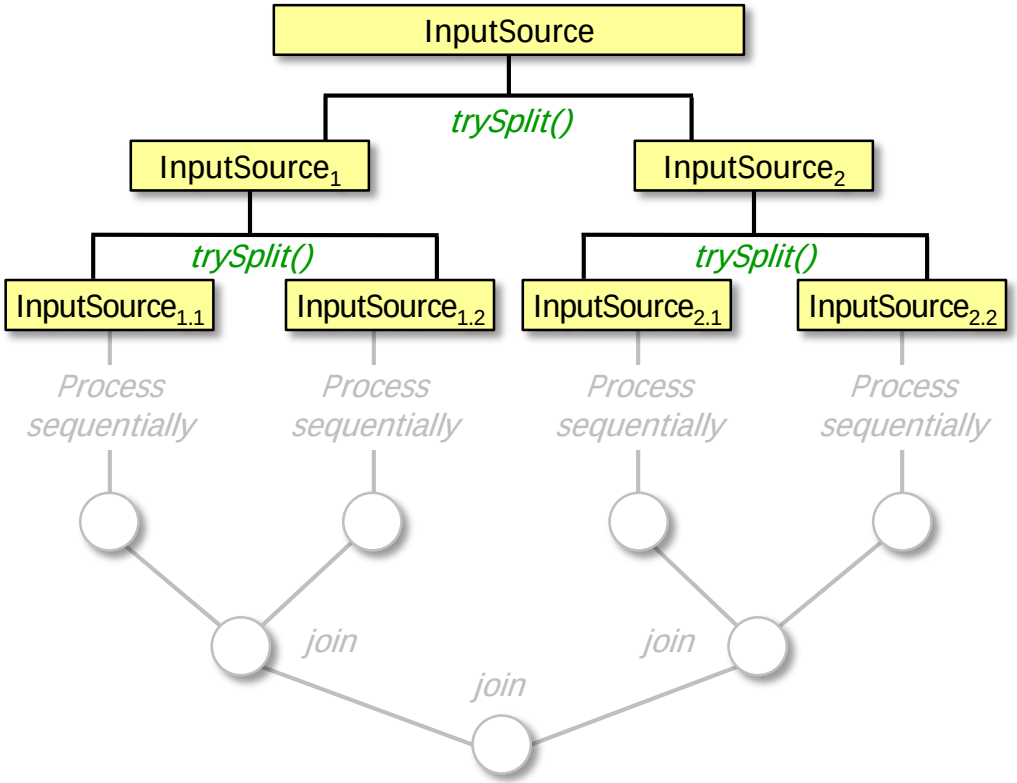

Implementing Concurrent & Non-Concurrent Collectors

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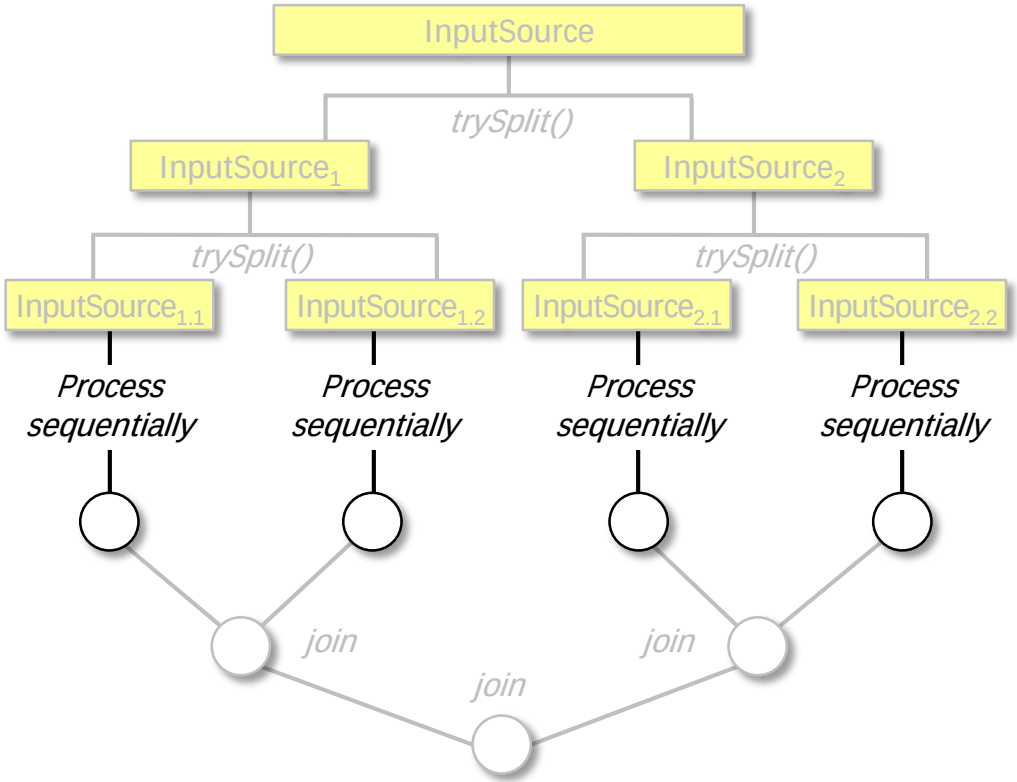
  - Each chunk is collected into a result container
    - e.g., a list or a map



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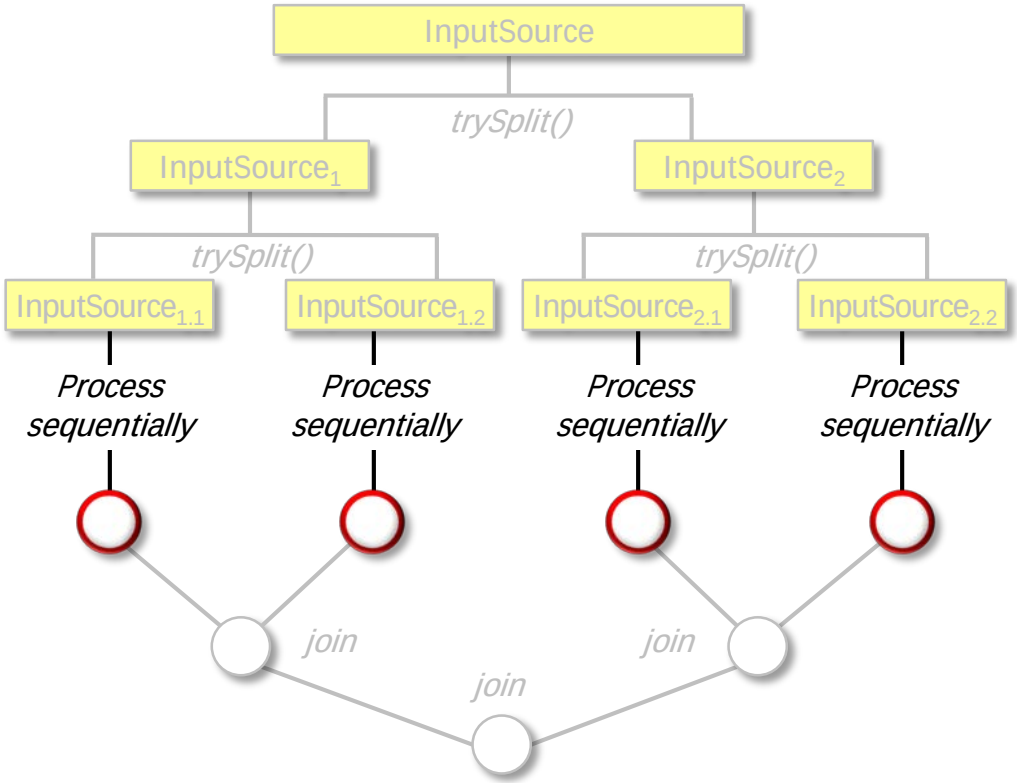

Different threads operate on different instances of intermediate result containers

Implementing Concurrent & Non-Concurrent Collectors

- A non-concurrent collector operates by merging sub-results
  - The input source is partitioned into chunks
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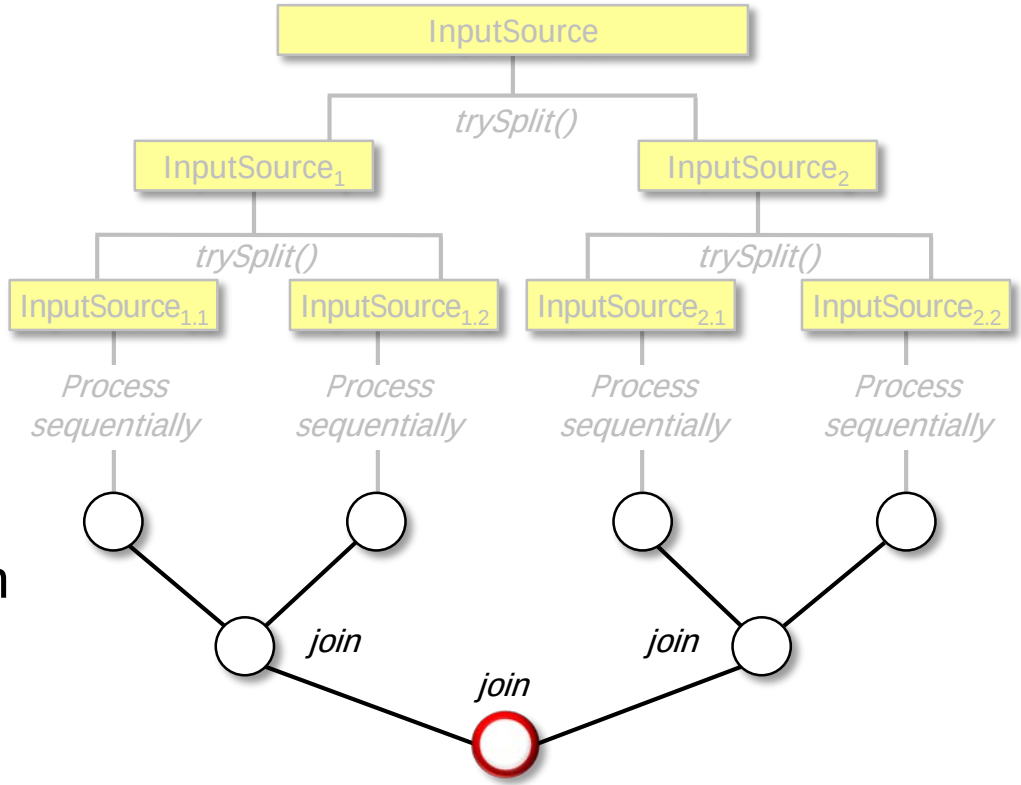
  - These sub-results are then merged into a final mutable result container
    - Only one thread in the fork-join pool is used to merge any pair of intermediate results



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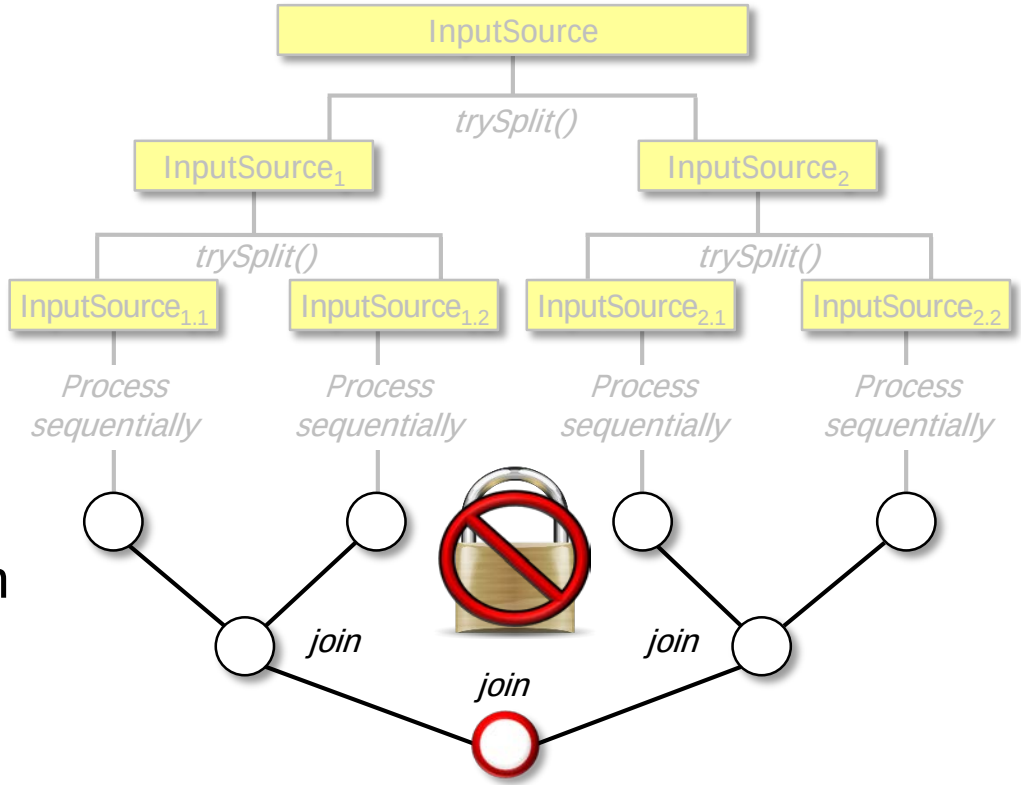

Thus there's no need for any synchronizers in a non-concurrent collector

Implementing Concurrent & Non-Concurrent Collectors

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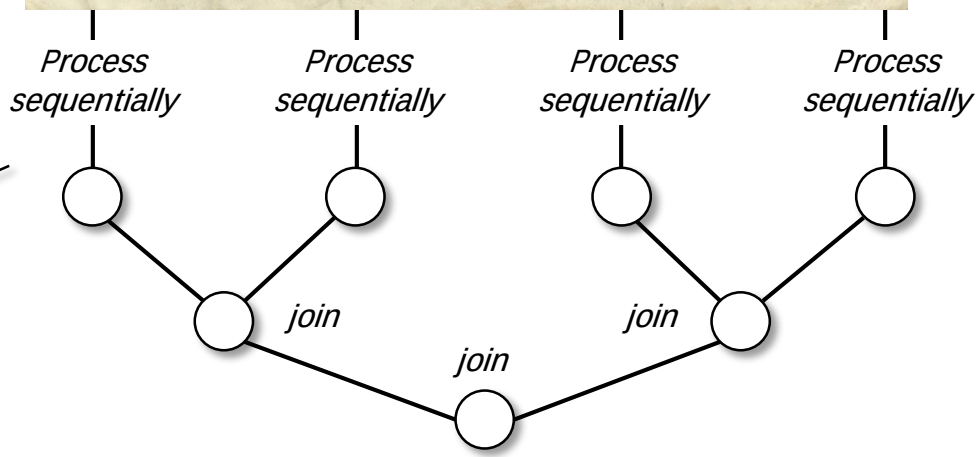


This process is safe & order-preserving, but merging is costly for containers like maps & sets

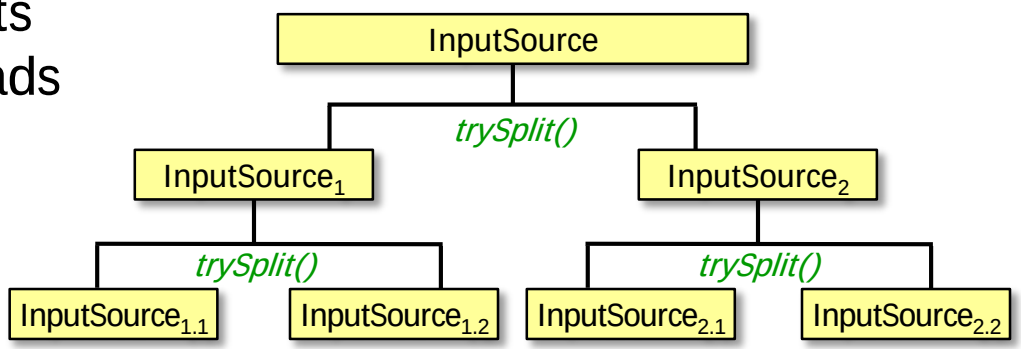
Implementing Concurrent & Non-Concurrent Collectors

- A concurrent collector creates one concurrent result container & inserts elements into it from multiple threads in a parallel stream

See stackoverflow.com/questions/22350288/parallel-streams-collectors-and-thread-safety

Implementing Concurrent & Non-Concurrent Collectors

- A concurrent collector creates one concurrent result container & inserts elements into it from multiple threads in a parallel stream
  - As usual, the input source is partitioned into chunks



Implementing Concurrent & Non-Concurrent Collectors

- A concurrent collector creates one concurrent result container & inserts elements into it from multiple threads in a parallel stream
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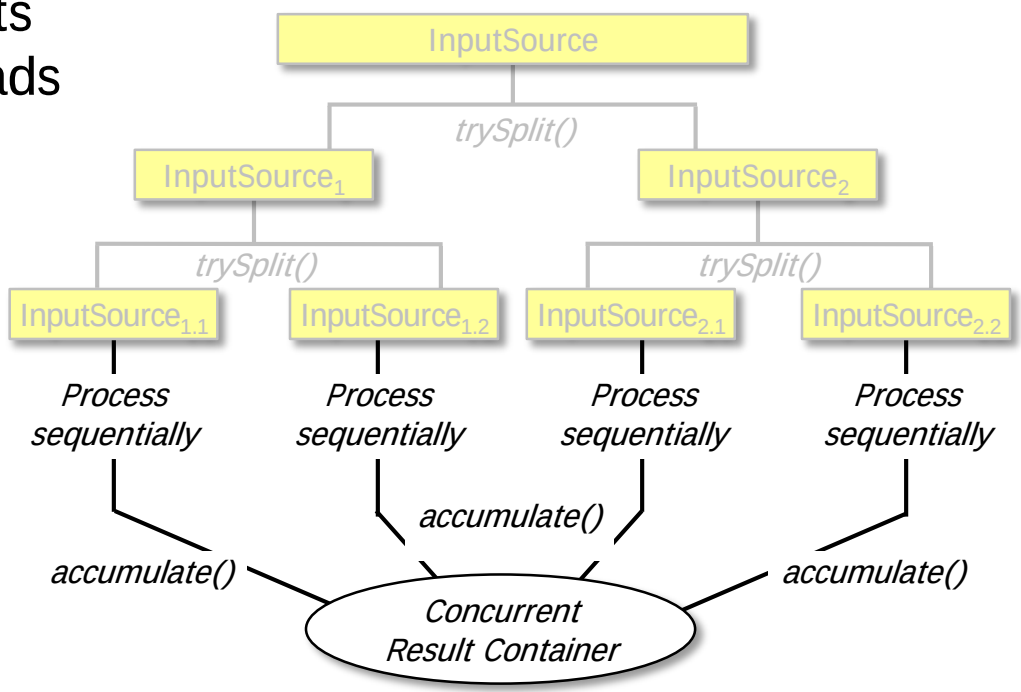
  - Each chunk is collected into one concurrent result container
    - e.g., a concurrent map or set



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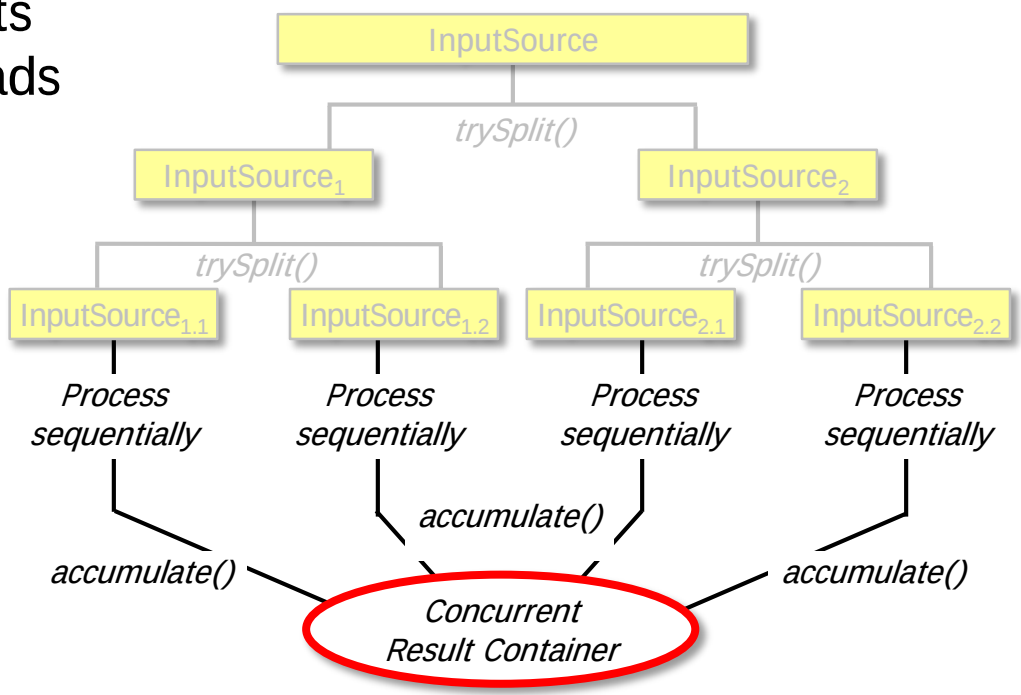
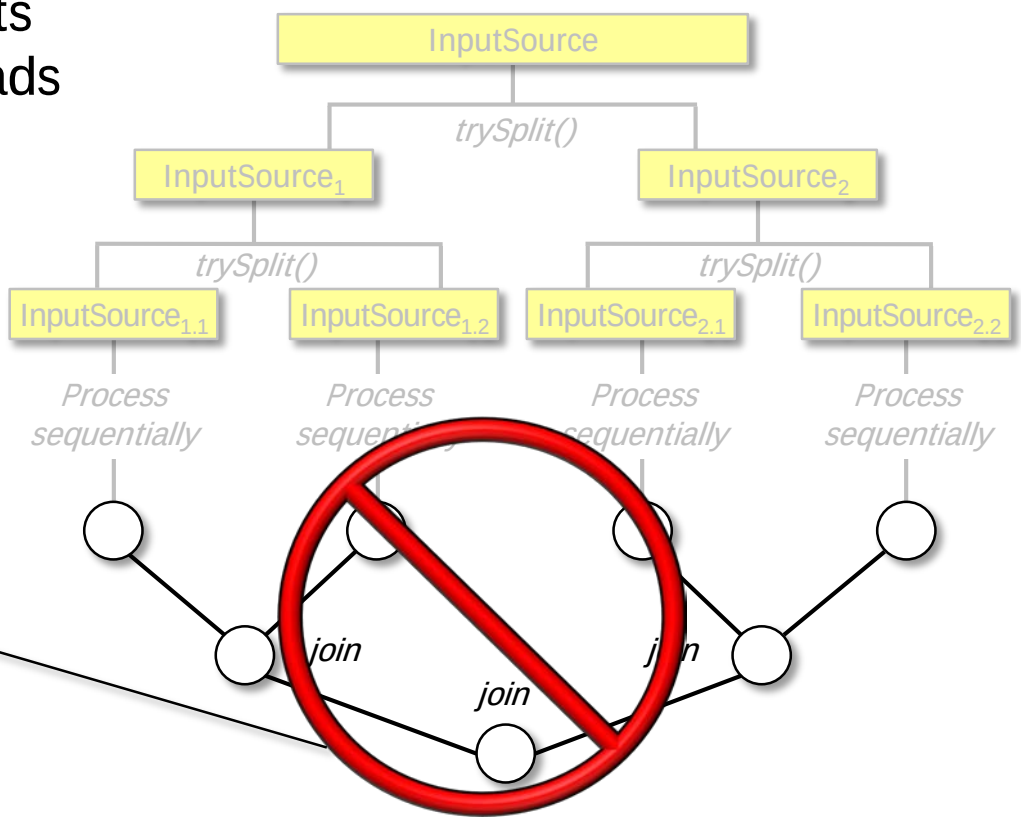


Different threads in a parallel stream share one concurrent result container

Implementing Concurrent & Non-Concurrent Collectors

- A concurrent collector creates one concurrent result container & inserts elements into it from multiple threads in a parallel stream
  - As usual, the input source is partitioned into chunks
  - Each chunk is collected into one concurrent result container

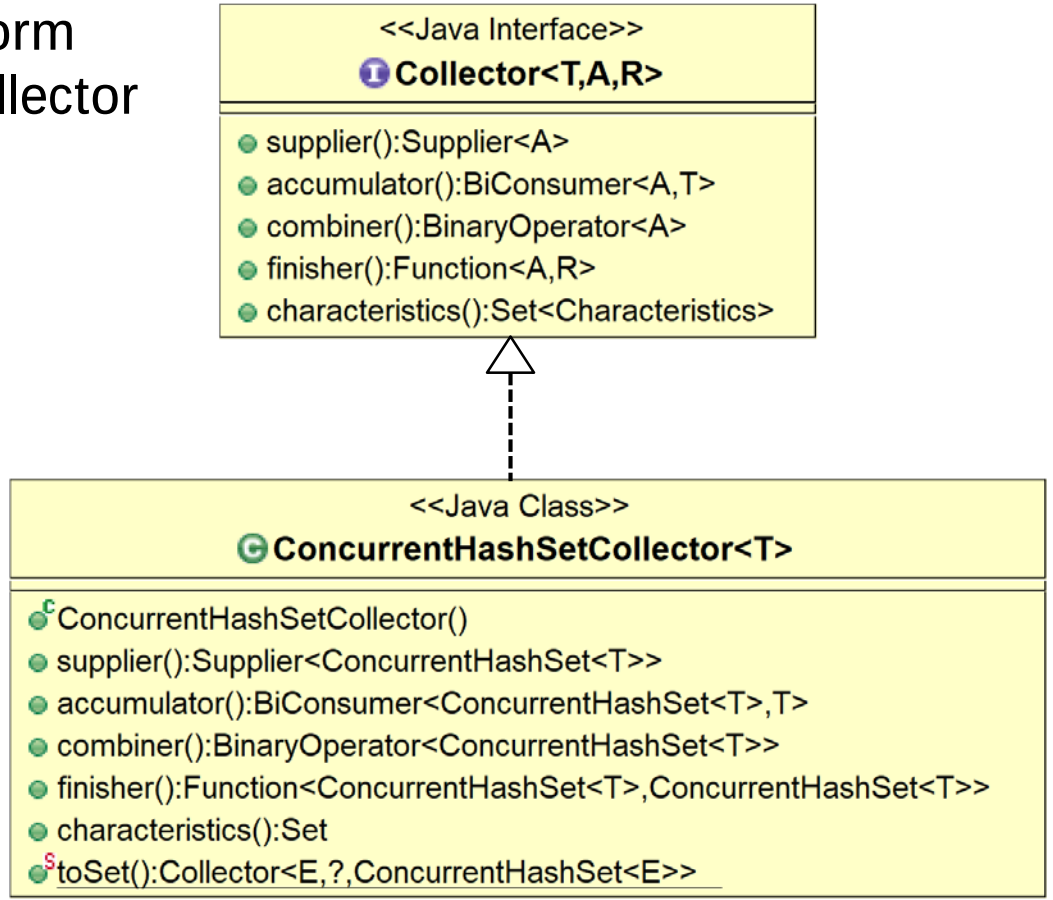


Thus there's no need to merge any intermediate sub-results!

Of course, encounter order is not preserved..

Implementing Concurrent & Non-Concurrent Collectors

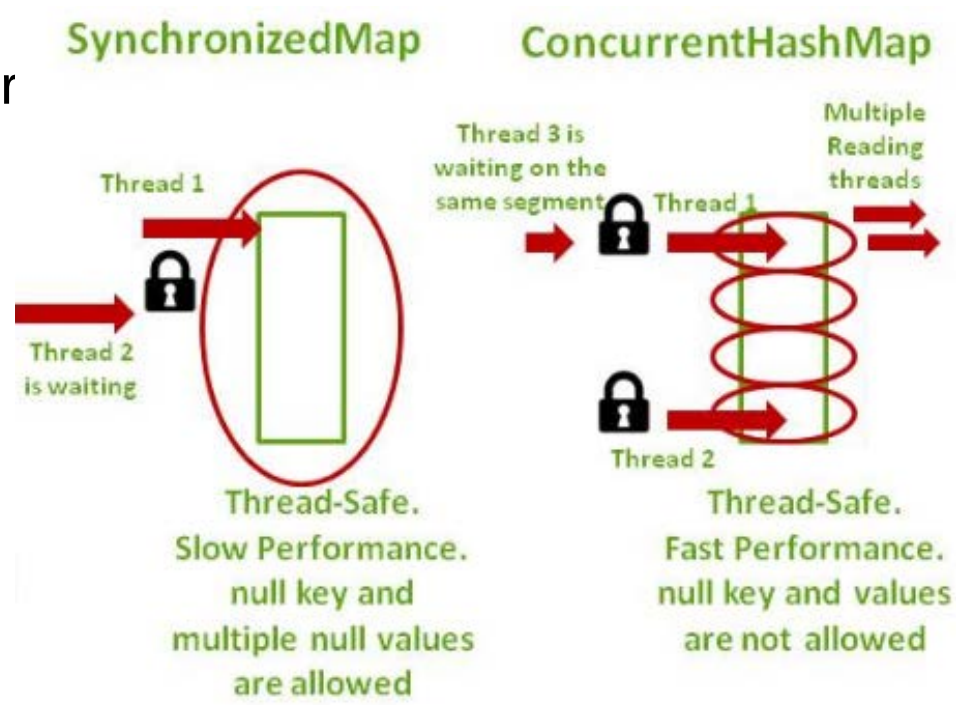
- A concurrent collector may perform better than a non-concurrent collector if merging costs are high



See github.com/douglascraigschmidt/LiveLessons/tree/master/Java8/ex14

Implementing Concurrent & Non-Concurrent Collectors

- A concurrent collector may perform better than a non-concurrent collector if merging costs are high
  - e.g., for a highly optimized result container like ConcurrentHashMap vs. merging HashMaps



See www.quora.com/What-is-the-difference-between-synchronize-and-concurrent-collection-in-Java

Implementing Concurrent & Non-Concurrent Collectors

- The Collector interface defines three generic types

<<Java Interface>>

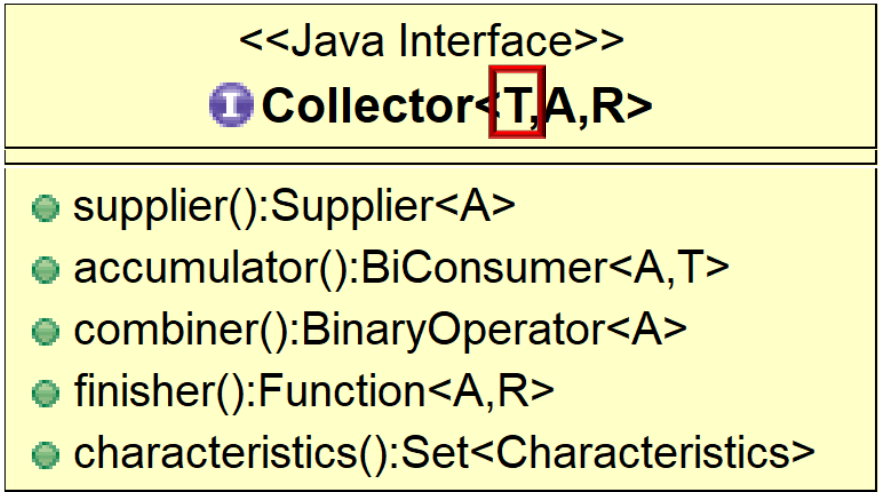
Collector<T,A,R>

- supplier():Supplier<A>
- accumulator():BiConsumer<A,T>
- combiner():BinaryOperator<A>
- finisher():Function<A,R>
- characteristics():Set<Characteristics>

See www.baeldung.com/java-8-collectors

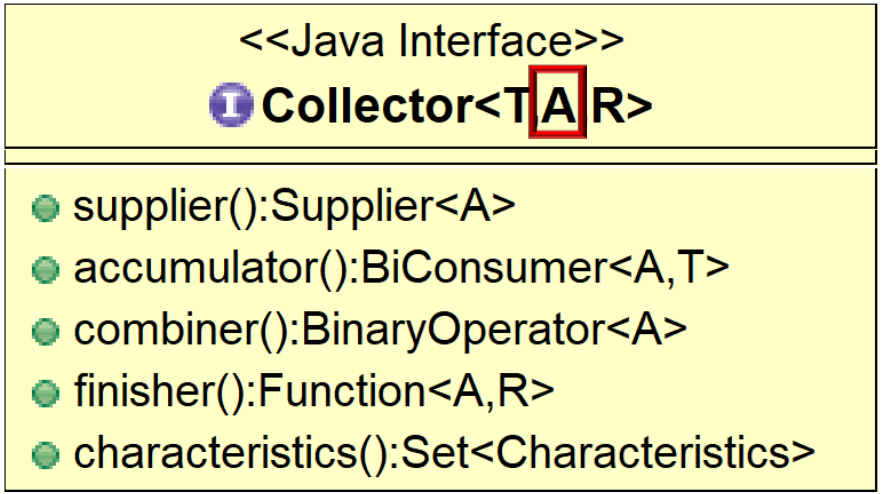
Implementing Concurrent & Non-Concurrent Collectors

- The Collector interface defines three generic types
  - **T** – The type of objects available in the stream
    - e.g., Integer, String, etc.



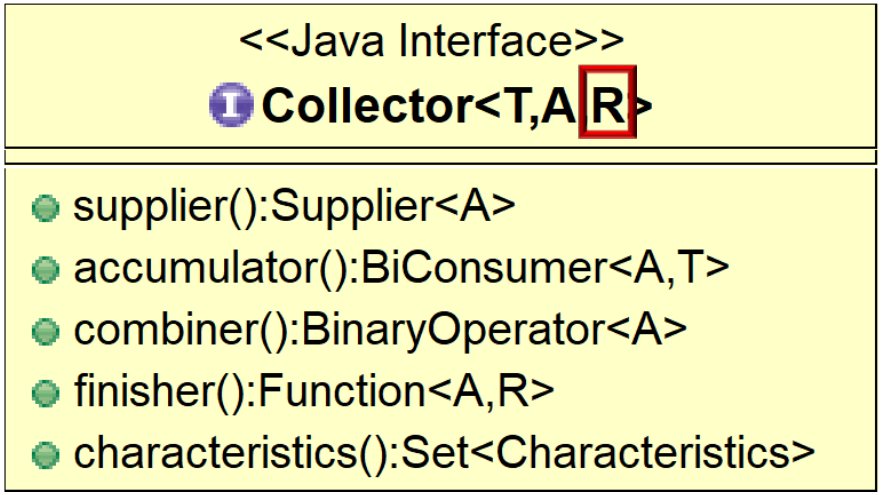
Implementing Concurrent & Non-Concurrent Collectors

- The Collector interface defines three generic types
  - T
  - **A** – The type of a mutable accumulator object for collection
    - e.g., ConcurrentHashSet or ArrayList of T



Implementing Concurrent & Non-Concurrent Collectors

- The Collector interface defines three generic types
  - T
  - A
  - **R** – The type of a final result
    - e.g., ConcurrentHashSet or ArrayList of T



See www.baeldung.com/java-8-collectors

Implementing Concurrent & Non-Concurrent Collectors

- Five methods are defined in the Collector interface

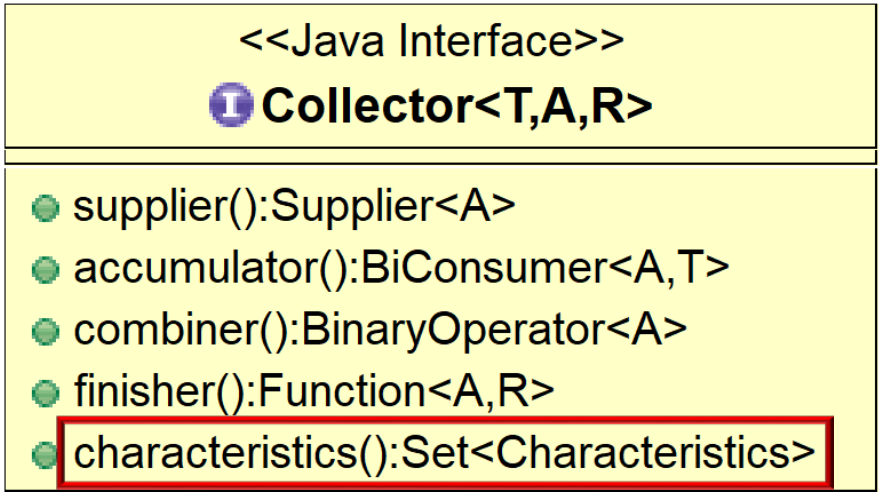
<<Java Interface>>

Collector<T,A,R>

- supplier():Supplier<A>
- accumulator():BiConsumer<A,T>
- combiner():BinaryOperator<A>
- finisher():Function<A,R>
- characteristics():Set<Characteristics>

Implementing Concurrent & Non-Concurrent Collectors

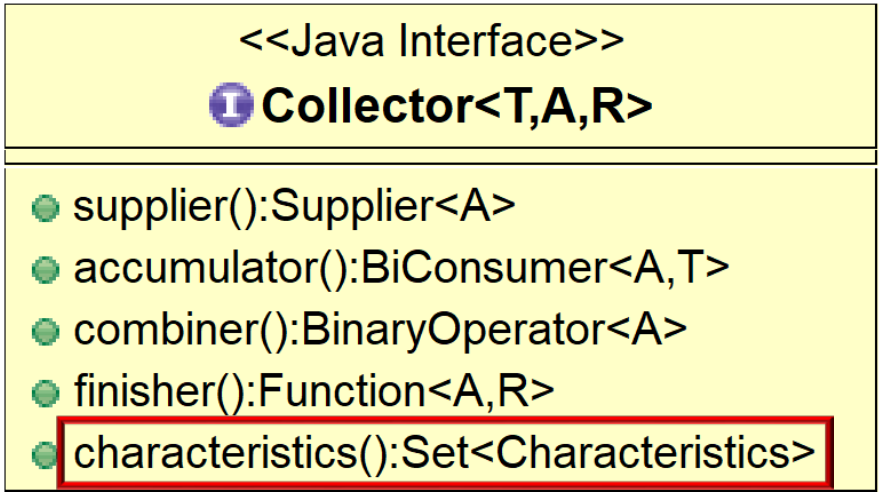
- Five methods are defined in the Collector interface
  - **characteristics()** – provides a stream with additional information used for internal optimizations, e.g.
    - UNORDERED
      - The collector need not preserve the encounter order



A concurrent collector *should* be UNORDERED, but a non-concurrent collector *can* be ORDERED

Implementing Concurrent & Non-Concurrent Collectors

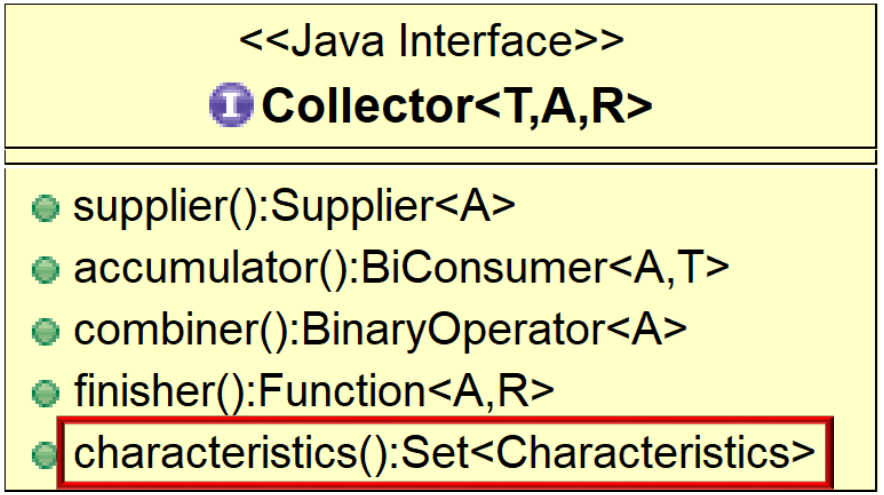
- Five methods are defined in the Collector interface
  - **characteristics()** – provides a stream with additional information used for internal optimizations, e.g.
    - UNORDERED
    - IDENTIFY_FINISH
      - The finisher() is the identity function so it can be a no-op
        - e.g. finisher() just returns null



A concurrent collector *should* be IDENTITY_FINISH, whereas a non-concurrent collector *could* be

Implementing Concurrent & Non-Concurrent Collectors

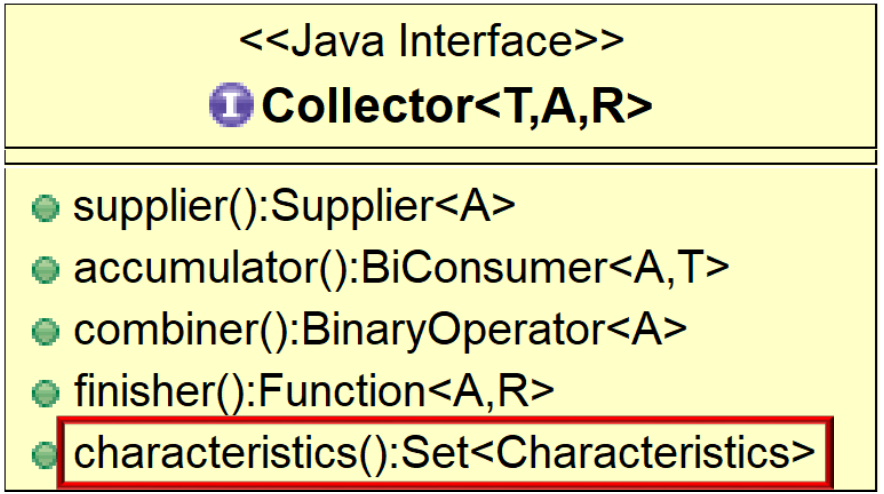
- Five methods are defined in the Collector interface
  - **characteristics()** – provides a stream with additional information used for internal optimizations, e.g.
    - UNORDERED
    - IDENTIFY_FINISH
    - CONCURRENT
      - The accumulator() method is called concurrently on the result container
        - Naturally, the mutable result container must be synchronized!!



A concurrent collector *should* be CONCURRENT, but a non-concurrent collector should *not* be!

Implementing Concurrent & Non-Concurrent Collectors

- Five methods are defined in the Collector interface
  - **characteristics()** – provides a stream with additional information used for internal optimizations, e.g.
    - UNORDERED
    - IDENTIFY_FINISH
    - CONCURRENT
      - The accumulator() method is called concurrently on the result container
      - The combiner() method is a no-op since it's not called at all



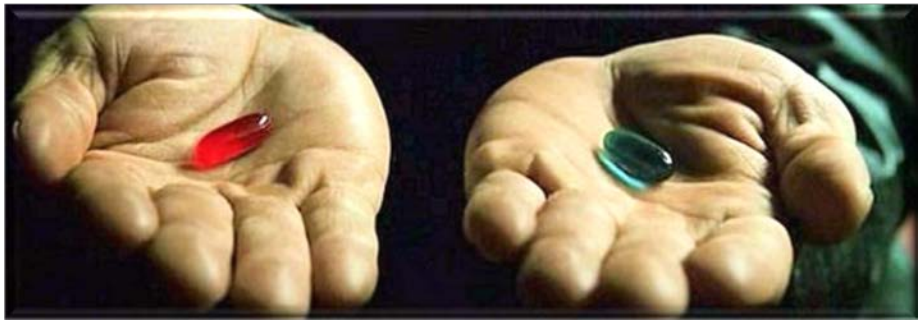
Implementing Concurrent & Non-Concurrent Collectors

- Five methods are defined in the Collector interface
  - **characteristics()** – provides a stream with additional information used for internal optimizations, e.g.
    - UNORDERED
    - IDENTIFY_FINISH
    - CONCURRENT

<<Java Interface>>

Collector<T,A,R>

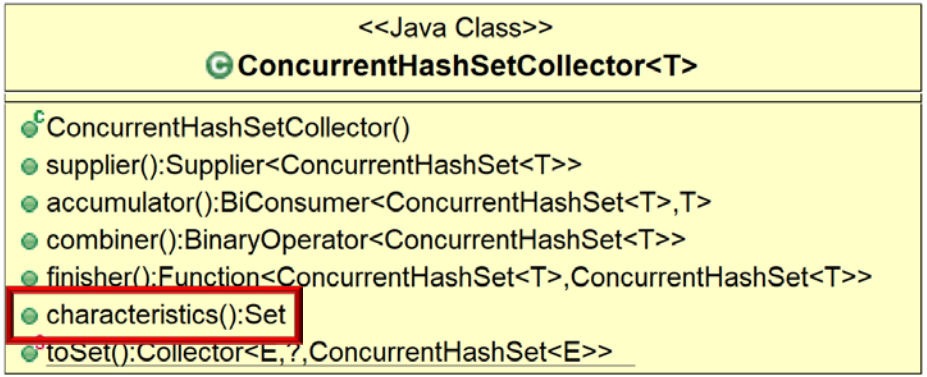
- supplier():Supplier<A>
- accumulator():BiConsumer<A,T>
- combiner():BinaryOperator<A>
- finisher():Function<A,R>
- characteristics():Set<Characteristics>



A non-concurrent collector can be used with either sequential or parallel streams

Implementing Concurrent & Non-Concurrent Collectors

- Five methods are defined in the Collector interface
  - **characteristics()** – provides a stream with additional information used for internal optimizations, e.g.
    - UNORDERED
    - IDENTIFY_FINISH
    - CONCURRENT

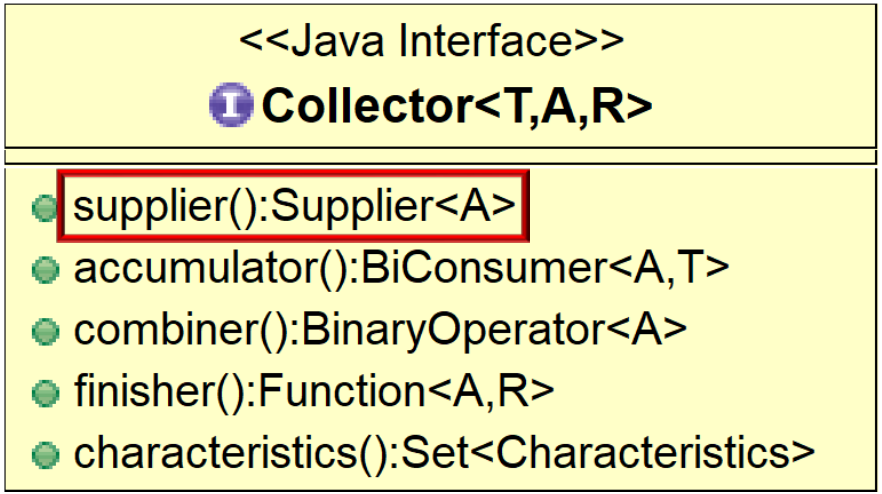



```
return Collections.unmodifiableSet
  (EnumSet.of(Collector.Characteristics.CONCURRENT,
   Collector.Characteristics.UNORDERED,
   Collector.Characteristics.IDENTITY_FINISH));
```

See github.com/douglascraigschmidt/LiveLessons/tree/master/Java8/ex14

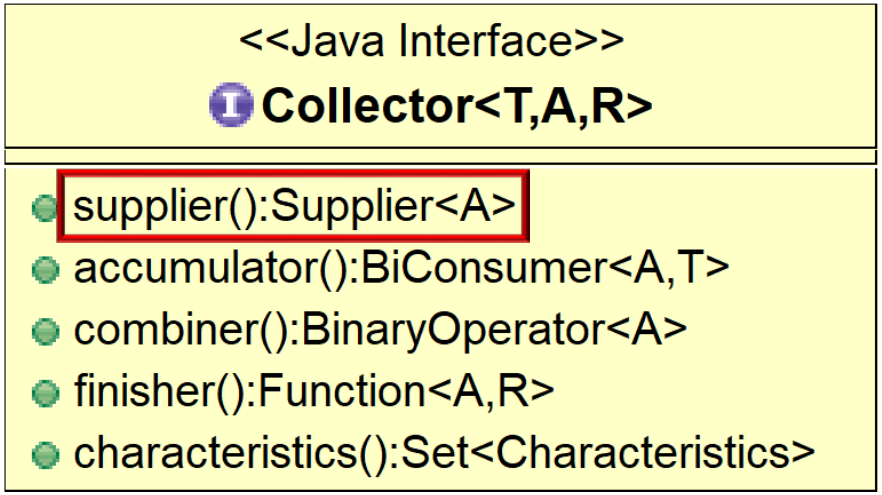
Implementing Concurrent & Non-Concurrent Collectors

- Five methods are defined in the Collector interface
  - characteristics()
  - **supplier()** – returns a supplier instance that generates an empty result container



Implementing Concurrent & Non-Concurrent Collectors

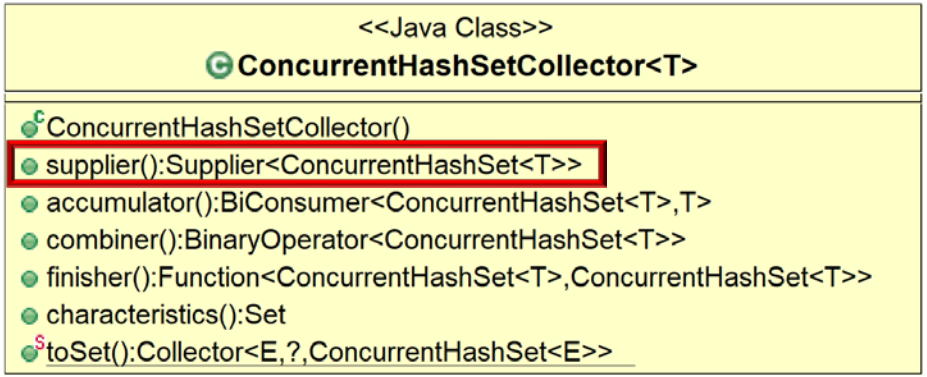
- Five methods are defined in the Collector interface
  - characteristics()
  - **supplier()** – returns a supplier instance that generates an empty result container, e.g.
    - `return ArrayList::new`



A non-concurrent collector has a different result container for each thread in a parallel stream

Implementing Concurrent & Non-Concurrent Collectors

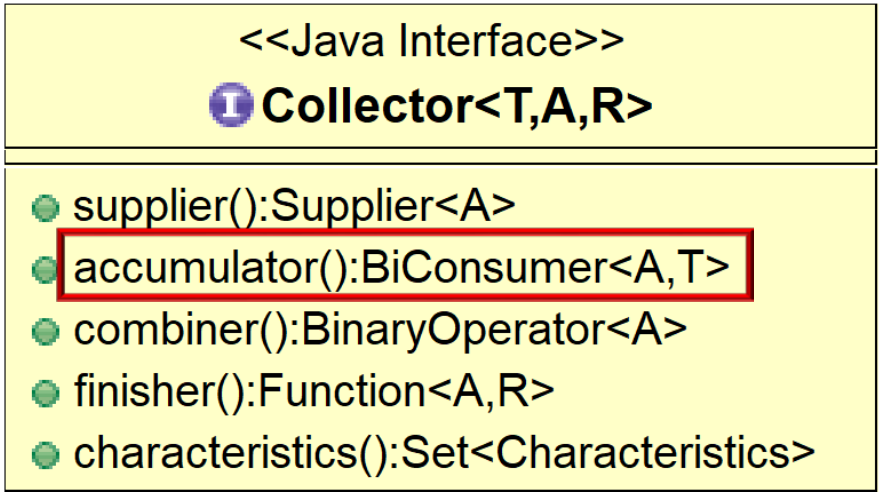
- Five methods are defined in the Collector interface
  - characteristics()
  - **supplier()** – returns a supplier instance that generates an empty result container, e.g.
    - `return ArrayList::new`
    - **`return ConcurrentHashSet::new`**



A concurrent collector has one result container shared by each thread in a parallel stream

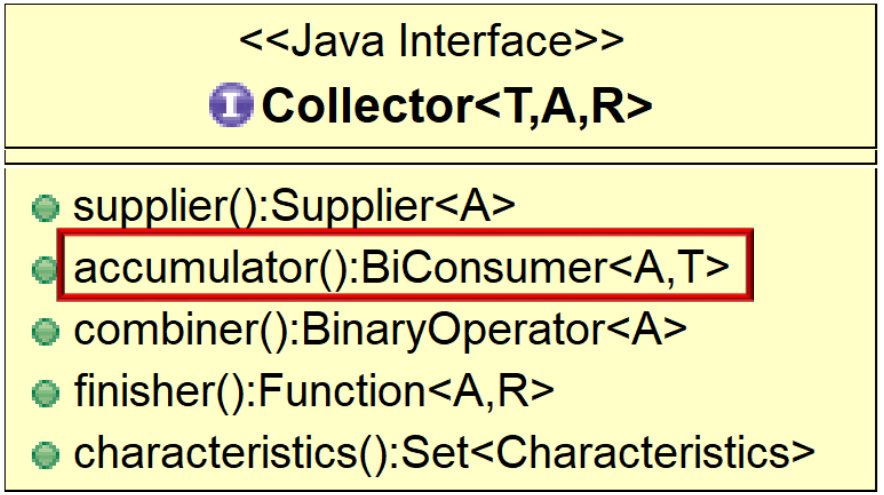
Implementing Concurrent & Non-Concurrent Collectors

- Five methods are defined in the Collector interface
  - characteristics()
  - supplier()
  - **accumulator()** – returns a biconsumer that adds a new element to result container



Implementing Concurrent & Non-Concurrent Collectors

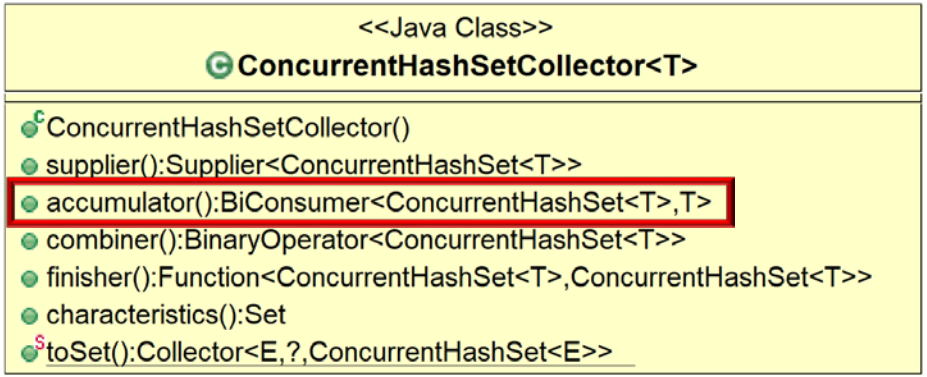
- Five methods are defined in the Collector interface
  - characteristics()
  - supplier()
  - **accumulator()** – returns a biconsumer that adds a new element to result container, e.g.
    - `return ArrayList::add`



A non-concurrent collector's methods should *not* be synchronized!

Implementing Concurrent & Non-Concurrent Collectors

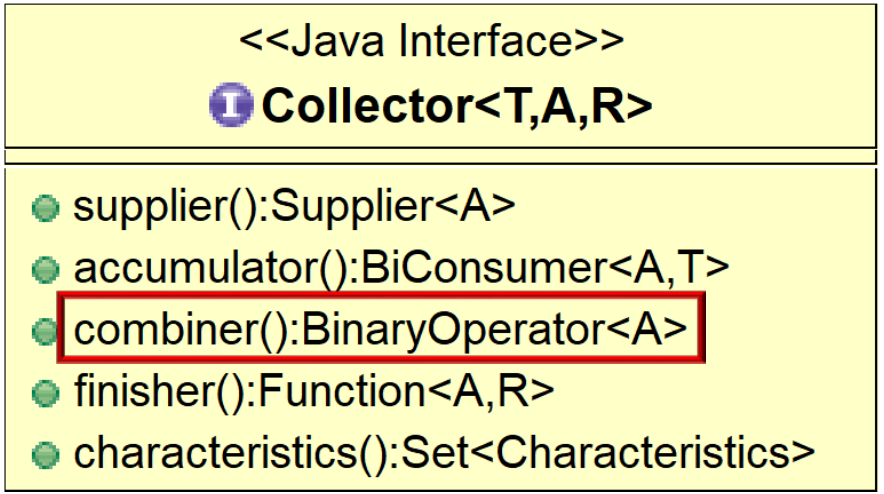
- Five methods are defined in the Collector interface
  - characteristics()
  - supplier()
  - **accumulator()** – returns a biconsumer that adds a new element to result container, e.g.
    - `return ArrayList::add`
    - **`return ConcurrentHashSet::add`**



A concurrent collector's methods *must* be synchronized!

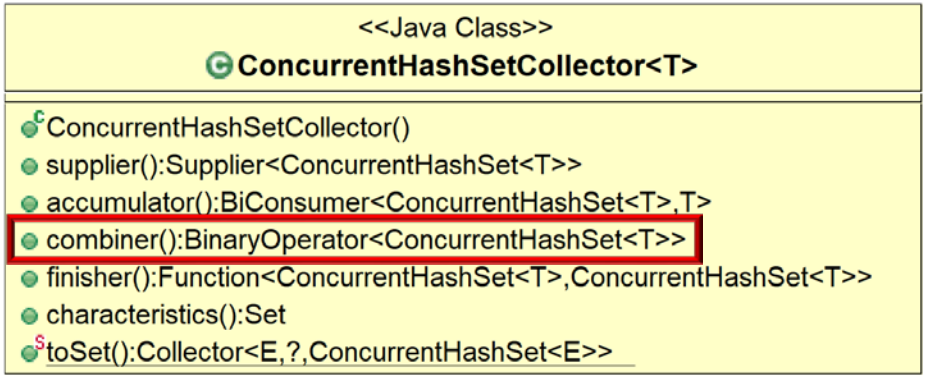
Implementing Concurrent & Non-Concurrent Collectors

- Five methods are defined in the Collector interface
  - characteristics()
  - supplier()
  - accumulator()
  - **combiner()** – returns a function that merges two result containers together



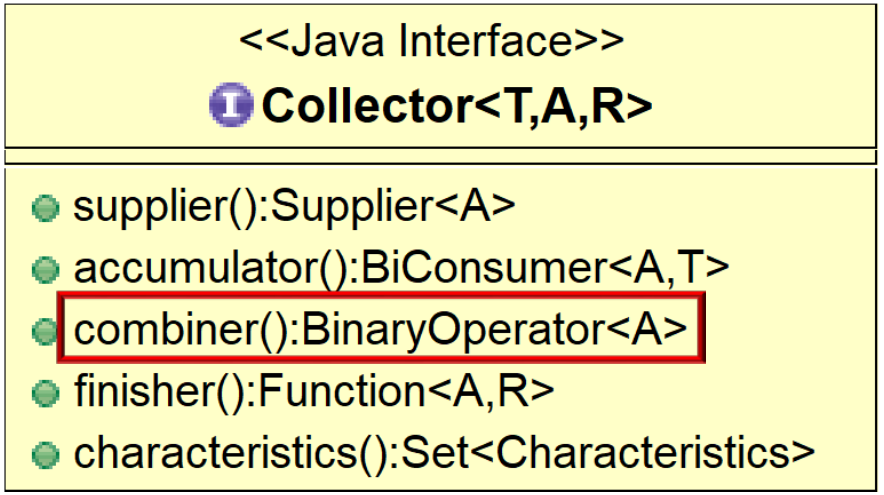
Implementing Concurrent & Non-Concurrent Collectors

- Five methods are defined in the Collector interface
  - characteristics()
  - supplier()
  - accumulator()
  - **combiner()** – returns a function that merges two result containers together, e.g.
    - `return (one, another) -> { one.addAll(another); return one; }`



Implementing Concurrent & Non-Concurrent Collectors

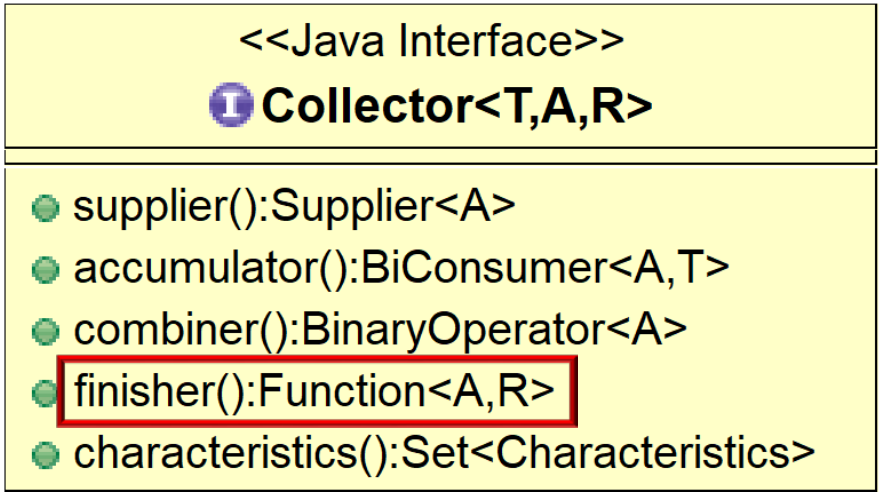
- Five methods are defined in the Collector interface
  - characteristics()
  - supplier()
  - accumulator()
  - **combiner()** – returns a function that merges two result containers together, e.g.
    - `return (one, another) -> { one.addAll(another); return one; }`
    - `return null`



The combiner() method is not called when CONCURRENT is set

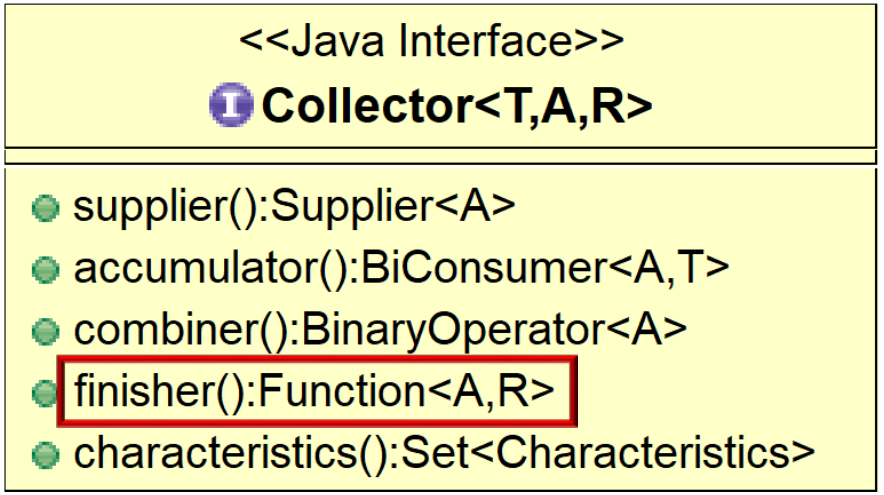
Implementing Concurrent & Non-Concurrent Collectors

- Five methods are defined in the Collector interface
  - characteristics()
  - supplier()
  - accumulator()
  - combiner()
  - **finisher()** – returns a function that converts the result container to final result type



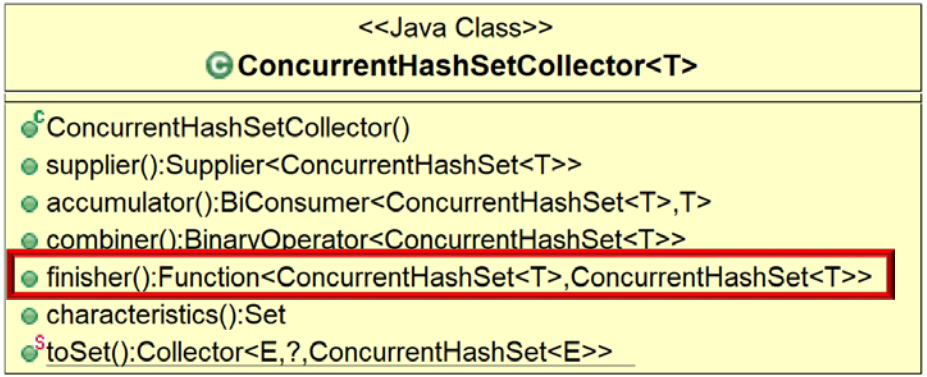
Implementing Concurrent & Non-Concurrent Collectors

- Five methods are defined in the Collector interface
  - characteristics()
  - supplier()
  - accumulator()
  - combiner()
  - **finisher()** – returns a function that converts the result container to final result type, e.g.
    - **`Function.identity()`** or something much more interesting!



Implementing Concurrent & Non-Concurrent Collectors

- Five methods are defined in the Collector interface
  - characteristics()
  - supplier()
  - accumulator()
  - combiner()
  - **finisher()** – returns a function that converts the result container to final result type, e.g.
    - `Function.identity()`
    - **`return null`**



The finisher() method is not called when IDENTITY_FINISHER is set

End of Java 8 Parallel Stream Internals (Part 5)