

Java Parallel Streams Internals: Order of Results for Operations

Douglas C. Schmidt

d.schmidt@vanderbilt.edu

www.dre.vanderbilt.edu/~schmidt



Professor of Computer Science

**Institute for Software
Integrated Systems**

**Vanderbilt University
Nashville, Tennessee, USA**



Learning Objectives in this Part of the Lesson

- Understand parallel stream internals, e.g.
 - Know what can change & what can't
 - Splitting, combining, & pooling mechanisms
 - Order of processing
 - Order of results
 - Overview
 - Collections that affect results order
 - Operations that affect results order



Learning Objectives in this Part of the Lesson

- Understand parallel stream internals, e.g.
 - Know what can change & what can't
 - Splitting, combining, & pooling mechanisms
 - Order of processing
 - Order of results
 - Overview
 - Collections that affect results order
 - Operations that affect results order

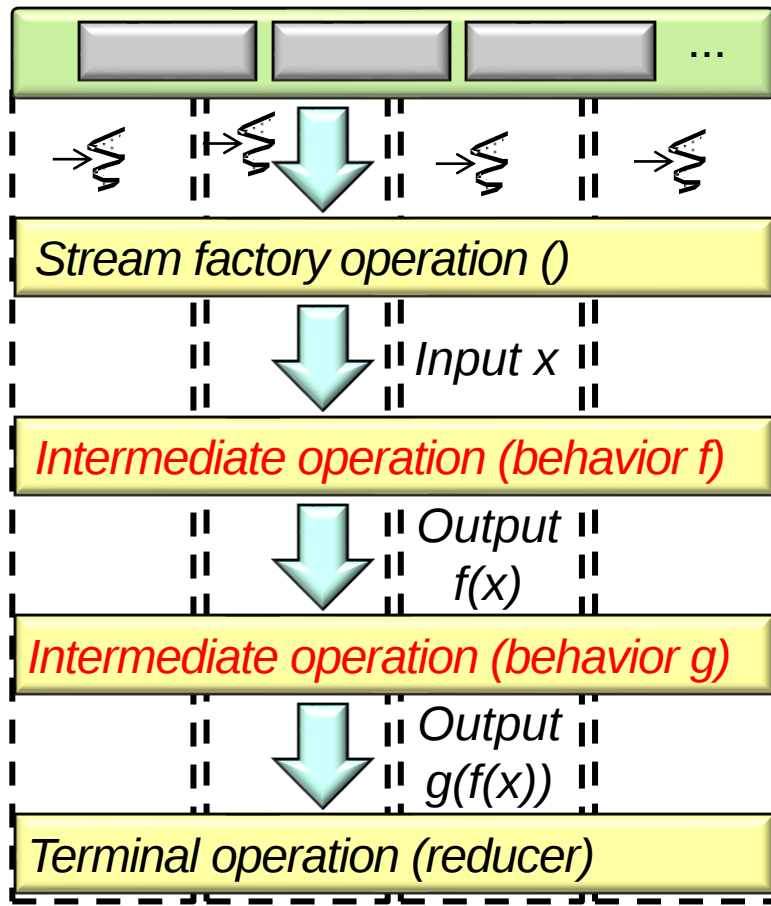
```
List<Integer> list =  
    Arrays.asList(1, 2, ...);  
  
Integer[] doubledList = list  
    .parallelStream()  
    .distinct()  
    .filter(x -> x % 2 == 0)  
    .map(x -> x * 2)  
    .limit(sOutputLimit)  
    .toArray(Integer[]::new);
```

Multiple examples are analyzed in detail

Intermediate Operations that Affect Results Order

Intermediate Operations that Affect Results Order

- Certain intermediate operations affect ordering behavior



Intermediate Operations that Affect Results Order

- Certain intermediate operations affect ordering behavior
 - e.g., `sorted()`, `unordered()`, `skip()`, & `limit()`

```
List<Integer> list = Arrays  
    .asList(2, 3, 1, 4, 2);
```

```
Integer[] doubledList = list  
    .parallelStream()  
    .distinct()  
    .filter(x -> x % 2 == 0)  
    .map(x -> x * 2)  
    .limit(sOutputLimit)  
    .toArray(Integer[]::new);
```

Intermediate Operations that Affect Results Order

- Certain intermediate operations affect ordering behavior
 - e.g., `sorted()`, `unordered()`, `skip()`, & `limit()`

```
List<Integer> list = Arrays  
    .asList(2, 3, 1, 4, 2);
```

*The encounter order is [2, 3, 1, 4, 2]
since list is ordered & non-unique*

```
Integer[] doubledList = list  
    .parallelStream()  
    .distinct()  
    .filter(x -> x % 2 == 0)  
    .map(x -> x * 2)  
    .limit(sOutputLimit)  
    .toArray(Integer[]::new);
```

Again, recall that “ordered” isn’t the same as “sorted”!

Intermediate Operations that Affect Results Order

- Certain intermediate operations affect ordering behavior
 - e.g., `sorted()`, `unordered()`, `skip()`, & `limit()`

```
List<Integer> list = Arrays  
    .asList(2, 3, 1, 4, 2);
```

```
Integer[] doubledList = list  
    .parallelStream()  
    .distinct()  
    .filter(x -> x % 2 == 0)  
    .map(x -> x * 2)  
    .limit(sOutputLimit)  
    .toArray(Integer[]::new);
```

Remove duplicate elements from the stream (a stateful intermediate operation)

See docs.oracle.com/javase/8/docs/api/java/util/stream/Stream.html#distinct

Intermediate Operations that Affect Results Order

- Certain intermediate operations affect ordering behavior
 - e.g., `sorted()`, `unordered()`, `skip()`, & `limit()`

Only process `sOutputLimit` elements in the stream (a stateful intermediate operation)

```
List<Integer> list = Arrays  
    .asList(2, 3, 1, 4, 2);
```

```
Integer[] doubledList = list  
    .parallelStream()  
    .distinct()  
    .filter(x -> x % 2 == 0)  
    .map(x -> x * 2)  
    .limit(sOutputLimit)  
    .toArray(Integer[]::new);
```

Intermediate Operations that Affect Results Order

- Certain intermediate operations affect ordering behavior
 - e.g., `sorted()`, `unordered()`, `skip()`, & `limit()`

```
List<Integer> list = Arrays  
    .asList(2, 3, 1, 4, 2);
```

```
Integer[] doubledList = list  
    .parallelStream()  
    .distinct()  
    .filter(x -> x % 2 == 0)  
    .map(x -> x * 2)  
    .limit(sOutputLimit)  
    .toArray(Integer[]::new);
```

*The result **must** be [4, 8], but the code is slow due to `limit()` & `distinct()` "stateful" semantics in parallel streams*

Intermediate Operations that Affect Results Order

- Certain intermediate operations affect ordering behavior
 - e.g., `sorted()`, `unordered()`, `skip()`, & `limit()`

```
List<Integer> list = Arrays  
    .asList(2, 3, 1, 4, 2);
```

```
Integer[] doubledList = list  
    .parallelStream()  
    .unordered()  
    .distinct()  
    .filter(x -> x % 2 == 0)  
    .map(x -> x * 2)  
    .limit(sOutputLimit)  
    .toArray(Integer[]::new);
```

This code runs faster since stream is unordered, so therefore `limit()` & `distinct()` incur less overhead

Intermediate Operations that Affect Results Order

- Certain intermediate operations affect ordering behavior
 - e.g., `sorted()`, `unordered()`, `skip()`, & `limit()`

```
List<Integer> list = Arrays  
    .asList(2, 3, 1, 4, 2);
```

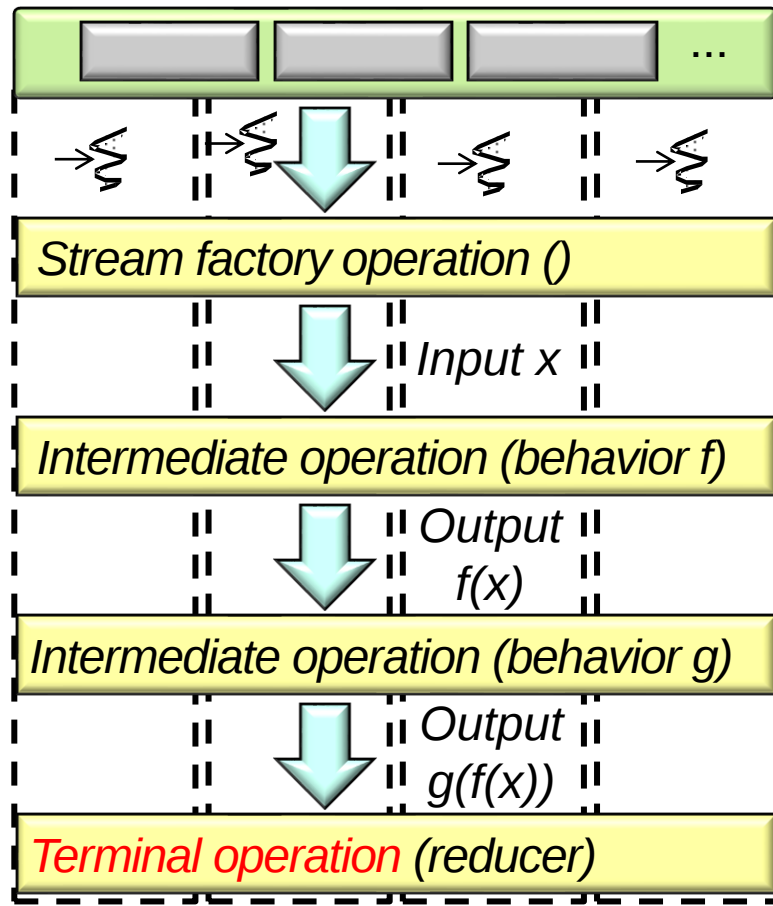
```
Integer[] doubledList = list  
    .parallelStream()  
    .unordered()  
    .distinct()  
    .filter(x -> x % 2 == 0)  
    .map(x -> x * 2)  
    .limit(sOutputLimit)  
    .toArray(Integer[]::new);
```

*Since encounter order needn't be maintained
the results could either be [8, 4] or [4, 8]*

Terminal Operations that Affect Results Order

Terminal Operations that Affect Results Order

- Certain terminal operations also affect ordering behavior



Terminal Operations that Affect Results Order

- Certain terminal operations also affect ordering behavior, e.g.
- `forEachOrdered()`

*The encounter order is [2, 3, 1, 4, 2]
since list is ordered & non-unique.*

```
List<Integer> list = Arrays  
    .asList(2, 3, 1, 4, 2);
```

```
List<Integer> results =  
    new ArrayList<>();
```

```
list  
    .parallelStream()  
    .distinct()  
    .filter(x -> x % 2 == 0)  
    .map(x -> x * 2)  
    .limit(sOutputLimit)  
    .forEachOrdered  
        (results::add);
```

Terminal Operations that Affect Results Order

- Certain terminal operations also affect ordering behavior, e.g.
- `forEachOrdered()`

This list supports unsynchronized insertions & removals of elements

```
List<Integer> list = Arrays  
    .asList(2, 3, 1, 4, 2);
```

```
List<Integer> results =  
    new ArrayList<>();
```

```
list  
    .parallelStream()  
    .distinct()  
    .filter(x -> x % 2 == 0)  
    .map(x -> x * 2)  
    .limit(sOutputLimit)  
    .forEachOrdered  
        (results::add);
```

Terminal Operations that Affect Results Order

- Certain terminal operations also affect ordering behavior, e.g.
 - `forEachOrdered()`

Results must appear in encounter order, but may be slow due to implicit synchronization in `forEachOrdered()`

```
List<Integer> list = Arrays  
    .asList(2, 3, 1, 4, 2);
```

```
List<Integer> results =  
    new ArrayList<>();
```

```
list  
    .parallelStream()  
    .distinct()  
    .filter(x -> x % 2 == 0)  
    .map(x -> x * 2)  
    .limit(sOutputLimit)  
    .forEachOrdered  
        (results::add);
```

Terminal Operations that Affect Results Order

- Certain terminal operations also affect ordering behavior, e.g.
 - `forEachOrdered()`
 - `forEach()`

Results need not appear in the encounter order, but may be faster since `forEach()` isn't synchronized

```
List<Integer> list = Arrays  
    .asList(2, 3, 1, 4, 2);
```

```
ConcurrentLinkedQueue  
    <Integer> results = new  
        ConcurrentLinkedQueue<>();
```

```
list  
    .parallelStream()  
    .distinct()  
    .filter(x -> x % 2 == 0)  
    .map(x -> x * 2)  
    .limit(sOutputLimit)  
    .forEach  
        (results::add);
```

Terminal Operations that Affect Results Order

- Certain terminal operations also affect ordering behavior, e.g.
 - `forEachOrdered()`
 - `forEach()`

However, this collection must support thread-safe insertions & removals!!

```
List<Integer> list = Arrays  
    .asList(2, 3, 1, 4, 2);
```

```
ConcurrentLinkedQueue  
<Integer> results = new  
    ConcurrentLinkedQueue<>();
```

```
list  
    .parallelStream()  
    .distinct()  
    .filter(x -> x % 2 == 0)  
    .map(x -> x * 2)  
    .limit(sOutputLimit)  
    .forEach  
        (results::add);
```

End of Java Parallel Streams Internals: Order of Results for Operations