Understand 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);
```

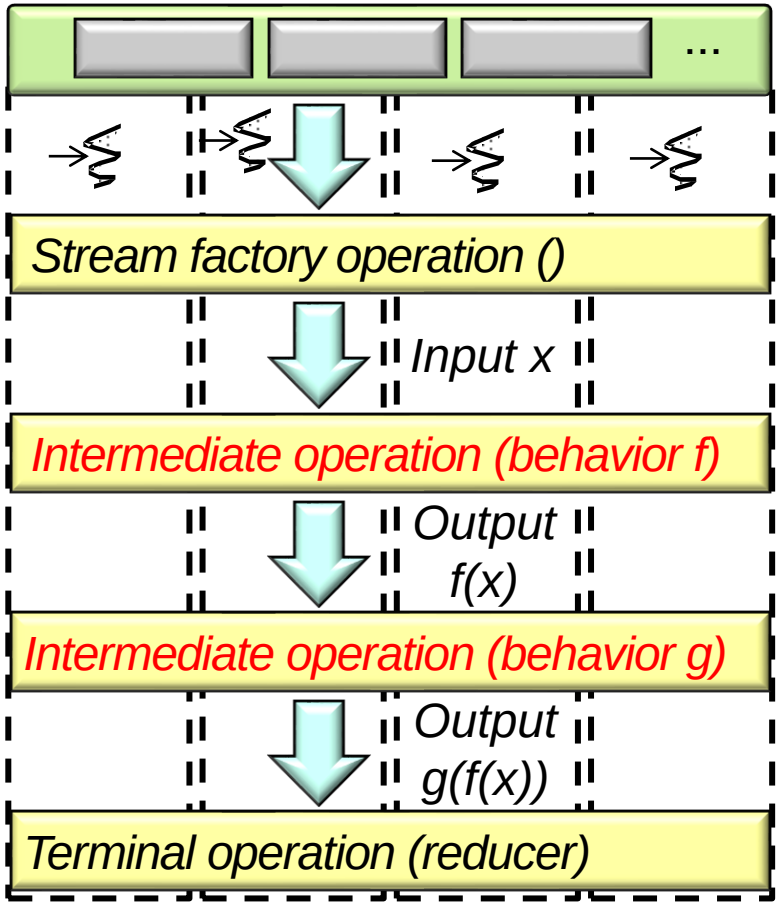
Multiple examples are analyzed in detail

See github.com/douglascraigschmidt/LiveLessons/tree/master/Java8/ex21

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);
```

See developer.ibm.com/languages/java/articles/j-java-streams-3-brian-goetz

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()

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

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

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

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

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

See docs.oracle.com/javase/8/docs/api/java/util/stream/BaseStream.html#unordered

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);
```

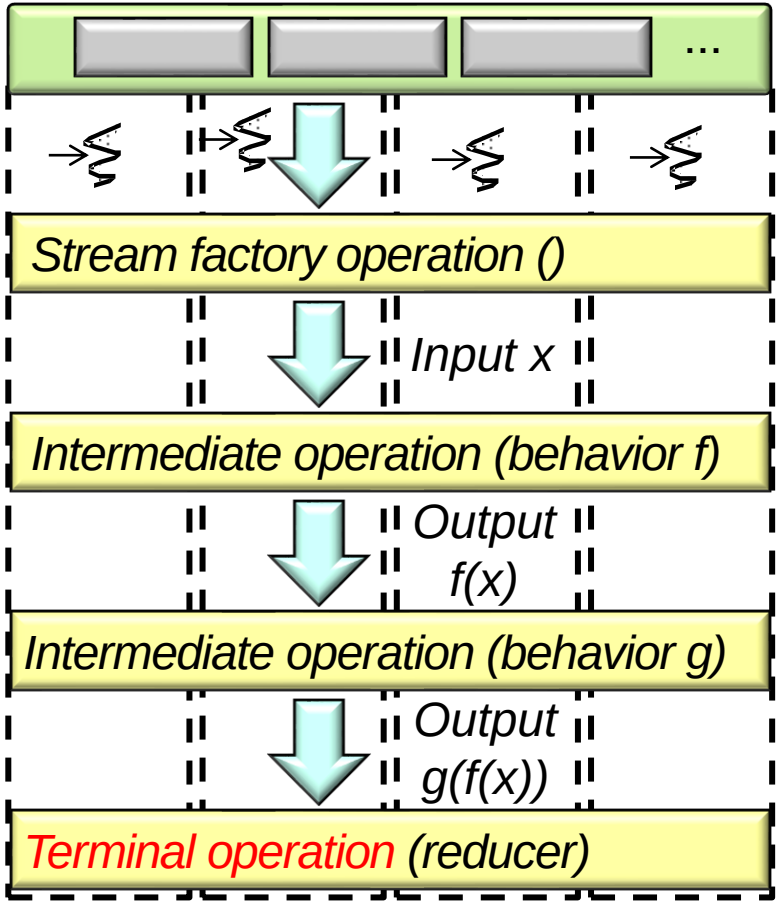
Since encounter order needn't be maintained the results could either be [8, 4] or [4, 8]

See developer.ibm.com/languages/java/articles/j-java-streams-3-brian-goetz

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()

```
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);
```

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

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

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);
```

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

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);
```

See docs.oracle.com/javase/8/docs/api/java/util/concurrent/ConcurrentLinkedQueue.html

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