Multicore Programming
Java Streams (Parallel)

Louis-Claude Canon
louis-claude.canon@univ-fcomte.fr

Bureau 414C

Master 1 computer science – Semester 8
Outline

Parallel Data Processing

Summary and References
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Parallel Data Processing
- Parallel Streams
  - Fork/join Framework
  - Spliterator

Summary and References
Parallel Data Processing  Parallel Streams

Thread Logic

Parallelizing a processing code requires:

1. splitting the data structure into chunks;
2. assigning each chunk to a different thread;
3. synchronizing the executions and combine the results.

Parallel streams hide this logic but each step can be customized.
parallel and sequential

A stream is either:

▶ sequential (by default or with the method `sequential`)
▶ or parallel (with the method `parallel`).

The last call in the stream construction wins.

```java
LongStream.rangeClosed(1, N)
    .parallel()
    .sum();
```
Setting the Number of Threads

There is by default one less threads than there are processors in the common pool (to let room for the main thread).

With the command line:

```
java -Djava.util.concurrent.ForkJoinPool.common.parallelism=3
```

In the code:

```java
System.setProperty("java.util.concurrent.ForkJoinPool.common.parallelism", "3");
ForkJoinPool forkJoinPool = new ForkJoinPool(3);
forkJoinPool.submit(() -> stream.terminalOp()).get();
```
Pitfalls

Necessary to understand the semantics to predict how the stream will be parallelized.

Performance issue:

```java
Stream.iterate(1L, i -> i + 1)
    .limit(n)
    .parallel()
    .reduce(0L, Long::sum);
```

Correctness issue:

```java
Accumulator accumulator = new Accumulator();
LongStream.rangeClosed(1, n)
    .parallel()
    .forEach(accumulator::add);
```
Measuring Performance

- Critical to test performance (even if the code is well understood).
- **Speed-up**: ratio of sequential execution time over parallel execution time. With $n$ cores, the ideal speed-up is $n$.
- Micro-benchmarking is difficult:
  - Cold-start (warm-up).
  - Variability (multiple iterations).
  - Java Microbenchmark Harness (JMH).
Stream Specifics

ORDERED flag and unordered() method:

- `findFirst` and `limit` rely on the order and require synchronization.
- `findAny` or `unordered` solve this issue.
- When the stream is ordered, prefer `forEachOrdered` over `forEach`.

SIZED flag:

- Prefer underlying data source that can be split efficiently (e.g. `ArrayList`, `range/rangeClosed`, and streams that convey their sizes).

Collectors:

- Be cautious of costly combiner methods.
- Use concurrent collectors when needed (`groupingByConcurrent` and `toConcurrentMap`).
General Advices

- Avoid boxing (prefer primitive stream specialization).
- Avoid parallelizing small streams with few data or processing.
- Measure performance and test validity.
Outline

Parallel Data Processing
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Summary and References
Parallel streams rely on the class `ForkJoinPool`, which is an implementation of `ExecutorService`.

Split tasks and distribute them on a pool of threads.
Fork recursively a task in smaller subtask until each subtask is small enough.

Sequential evaluation

Evaluate all subtasks in parallel

Sequential evaluation

Sequential evaluation

Sequential evaluation

Recombine the partial results
Work-Stealing

- Creation of more tasks than available threads because tasks may be heterogeneous.
- Each thread starts by splitting tasks, putting them in their execution queue.
- Once a task is small enough, it is executed.
- When a thread finishes all tasks in its execution queue, it steals waiting tasks from the other queues.
Worker 1: 4
Worker 2: 2
Worker 3: 2
Worker 4: 4

Worker 2: steal 2
Worker 3: steal 1, steal 1
Worker 4: steal 1, steal 1

Worker 1: split 2
Worker 2: split 1, split 1
Worker 3: split 1, split 1
Worker 4: split 1, split 1

All workers run.
Outline

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Summary and References
**Interface**

Splitable iterator: define how to split the stream that is iterated.

```java
public interface Spliterator<T> {
    boolean tryAdvance(Consumer<T> action);
    Spliterator<T> trySplit();
    long estimateSize();
    int characteristics();
}
```
trySplit

Logic for splitting data stream.

```java
public Spliterator trySplit() {
    if (currentSize < MIN_SIZE)
        return null;
    long half = currentSize / 2;
    currentSize -= half;
    return new Spliterator(half);
}
```
tryAdvance

Feeds the consumer with the next stream element.

```java
public boolean tryAdvance(Consumer action) {
    if (currentSize == 0)
        return false;
    action.accept(nextValue());
    currentSize--;
    return true;
}
```
The size can be estimated (used for balancing work).

```java
public long estimateSize() {
    return currentSize;
}
```
characteristics
Information to control or optimize the usage of the spliterator.

```java
public int characteristics() {
    return ORDERED + DISTINCT + SORTED + CONCURRENT
        + SIZED + SUBSIZED + NONNULL + IMMUTABLE;
}
```

**ORDERED**  the order of the elements must be enforced

**DISTINCT**  all elements are distinct

**SORTED**  elements are sorted

**CONCURRENT**  the modification of the stream source is thread-safe

**SIZE**  the estimated size is precise

**SUBSIZED**  all created spliterators are SIZED

**NON-NULL**  all elements are non-null

**IMMUTABLE**  the stream source cannot be modified
Demonstration

Compute the sum of all square numbers between 1 and $n$.

```java
var start = System.nanoTime();
IntStream.rangeClosed(1, n)
    .parallel()
    .peek(i -> System.out.println(Thread.currentThread().getName()))
    .filter(i -> {
        var x = Math.floor(Math.sqrt(i));
        return x * x == i;
    })
    .sum();
(System.nanoTime() - start) * 1e9;
```
Outline

Parallel Data Processing

Summary and References
Parallel Data Processing

- Internal iteration allows processing a stream in parallel without the thread logic.
- Always check and measure.
- Parallel execution improve performance when processing is significant.
- But using the correct data structure can be even more efficient.
- The fork/join framework is used to recursively split streams and distribute them with a work-stealing approach.
- A Spliterator defines how a parallel stream can split the data it traverses.
Official Documentation

- Documentation of interface Spliterator