Multicore Programming
Java Streams (Advanced)

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

Bureau 414C

Master 1 computer science – Semester 8
Outline

Special Streams

Collectors

Summary and References
Outline

Special Streams
- Numeric Streams
- Building Streams
- Infinite Streams

Collectors

Summary and References
Primitive Stream Specializations

- IntStream, DoubleStream and LongStream.
- Avoid unboxing and boxing (more efficient data representation).
- Additional methods for efficiency and convenience: min, max, sum, average, etc.
Java: Boxing and Unboxing

- Collection of primitive type are forbidden in Java (e.g. List<int>).
- Boxing consists in encapsulating a primitive type into an object (e.g. Integer).
- Boxing and unboxing are performed automatically when needed.
- Working on boxed values is costly.
To and From a Primitive Stream

mapToInt:

```java
int calories = menu.stream()
    .mapToInt(Dish::getCalories)
    .sum();
```

boxed:

```java
Stream<Integer> stream = intStream.boxed();
```
Specialized Optionals

- `OptionalInt`
- `OptionalDouble`
- `OptionalLong`
Outline

Special Streams
  Numeric Streams
  Building Streams
  Infinite Streams

Collectors

Summary and References
From Values

Stream<String> stream =
    Stream.of("Modern ", "Java ", "In ", "Action");
From Arrays

```java
int[] numbers = {2, 3, 5, 7, 11, 13};
int sum = Arrays.stream(numbers).sum();
```
From a Collection

```java
List<Integer> numbers = Arrays.asList(1, 2, 1, 3, 3, 2, 4);
int sum = numbers.stream()
    .mapToInt(Integer::intValue)
    .sum();
```
From Numeric Ranges

```java
IntStream evenNumbers = IntStream.rangeClosed(1, 100)
    .filter(n -> n % 2 == 0);
```

- range is exclusive
- rangeClosed is inclusive
long uniqueWords = 0;
try (Stream<String> lines = Files.lines(Paths.get("data.txt"),
                                       Charset.defaultCharset())) {
    uniqueWords = lines
                  .flatMap(line -> Arrays.stream(line.split(" ")))
                  .distinct()
                  .count();
} catch (IOException e) {
}"
From Nullable

From Java 9:

```java
String homeValue = System.getProperty("home");
Stream<String> homeValueStream =
    homeValue == null ? Stream.empty() : Stream.of(value);

Stream<String> homeValueStream =
    Stream.ofNullable(System.getProperty("home"));
```

A stream with a null value differs from an empty stream.
Outline

Special Streams
  Numeric Streams
  Building Streams
  Infinite Streams

Collectors

Summary and References
iterate

```java
Stream.iterate(0, n -> n + 2)
        .limit(10)
        .forEach(System.out::println);

IntStream.iterate(0, n -> n < 100, n -> n + 4)
        .forEach(System.out::println);
```

- Needs a short-circuiting operation to terminate.
- No unbounded intermediate stateful operation (distinct and sorted).
generate

```java
Stream.generate(Math::random)
    .limit(5)
    .forEach(System.out::println);
```

- Requires a stateful (with a mutable state) supplier.
Outline

Special Streams

Collectors

Reducing and Summarizing
Other Single-Level Collectors
Grouping and Partitioning
Custom Collector

Summary and References
Collect the final result as the terminal operation.

- Require a Collector object as its parameter.
- A collector is designed to work on a stream.
- No relation with Collection.
- Several ways to define such collectors in class Collectors.

```java
stream.collect(toList());
```
toList
Outline

Special Streams

Collectors

Reducing and Summarizing
Other Single-Level Collectors
Grouping and Partitioning
Custom Collector

Summary and References
maxBy and minBy

```java
Comparator<Dish> dishCaloriesComparator = Comparator.comparing(Dish::getCalories);
Optional<Dish> mostCalorieDish = menu.stream()
    .collect(maxBy(dishCaloriesComparator));
```

Equivalence:

```java
Optional<Dish> mostCalorieDish = menu.stream()
    .max(dishCaloriesComparator);
```
Summarizing: `summingInt`, `counting`, `averagingInt` and `summarizingInt`

```java
int totalCalories = menu.stream()
    .collect(summingInt(Dish::getCalories));
long count = menu.stream()
    .collect(counting());
double avgCalories = menu.stream()
    .collect(averagingInt(Dish::getCalories));
IntSummaryStatistics menuStatistics = menu.stream()
    .collect(summarizingInt(Dish::getCalories));
```
Reducing

```java
int totalCalories = menu.stream()
    .collect(reducing(0, Dish::getCalories,
                      Integer::sum));
```

- Generalization of previous summarizing operations.
- First apply map function (e.g. getCalories), and then performs the reduction operation (e.g. sum).

Equivalence:

```java
int totalCalories = menu.stream()
    .mapToInt(Dish::getCalories)
    .reduce(0, Integer::sum);
```
joining

```java
String shortMenu = menu.stream()
    .map(Dish::getName)
    .collect(joining("", ""));
```

Equivalence:

```java
String shortMenu = menu.stream()
    .map(Dish::getName)
    .reduce((a, b) -> a + ", " + b)
    .orElse("" )
```
Outline

Special Streams

Collectors

collect
Reducing and Summarizing
Other Single-Level Collectors
Grouping and Partitioning
Custom Collector

Summary and References
filtering

```java
List<Dish> caloricDishes = menu.stream()
    .collect(filtering(dish -> dish.getCalories() > 500,
                      toList()));
```

Result:

```
french fries, pizza, pork, beef
```

Equivalence:

```java
List<Dish> caloricDishes = menu.stream()
    .filter(dish -> dish.getCalories() > 500)
    .toList();
```
mapping

```java
List<String> dishNames = menu.stream()
    .collect(mapping(Dish::getName,
                   toList()));
```

- flatMapping when generating a stream for each object instead of an object only (merge the streams).

Equivalence:

```java
List<String> dishNames = menu.stream()
    .map(Dish::getName)
    .toList();
```
collectingAndThen

To apply a specific function on the result of the collection operation:

```java
Dish mostCaloric = menu.stream()
    .collect(collectingAndThen(
        maxBy(comparing(Dish::getCalories)),
        Optional::get));
```

Equivalence:

```java
Dish mostCaloric = menu.stream()
    .max(comparing(Dish::getCalories))
    .get();
```
Intermediate operation, transformation and collect

Example with reduce and reducing:

- reducing is like reduce but for a multi-level reduction.
- reduce must work on an immutable state (the accumulating and combining functions should have no side effect) because it can be parallelized.
- collect builds incrementally a mutable object (more efficient for strings because of StringBuilder).
Outline

Special Streams

Collectors

collect
Reducing and Summarizing
Other Single-Level Collectors

Grouping and Partitioning

Custom Collector

Summary and References
Example without Streams

```java
Map<Currency, List<Transaction>> transByCurr =
    new HashMap<>();
for (Transaction transaction : transactions) {
    Currency currency = transaction.getCurrency();
    List<Transaction> transForCurr =
        transByCurr.get(currency);
    if (transForCurr == null) {
        transForCurr = new ArrayList<>();
        transByCurr.put(currency, transForCurr);
    }
    transForCurr.add(transaction);
}
```
Collectors  Grouping and Partitioning

**groupingBy**

```java
Map.Currency, List.Transaction> transByCurr =
transactions.stream()
    .collect(groupingBy(Transaction::getCurrency));
```
Second Example

```java
Map<String, List<Dish>> dishesByType =
    menu.stream()
    .collect(groupingBy(Dish::getType));
```
Stream

Next item

Apply

Classification function

Key

FISH

Grouping map

FISH

MEAT

OTHER

Classify item into list

salmon

pork

beef

chicken

pizza

rice

french fries
Grouping without Classification Function

```java
public enum CaloricLevel { DIET, NORMAL, FAT }

Map<CaloricLevel, List<Dish>> dishesByCaloricLevel =
    menu.stream()
    .collect(groupingBy(dish -> {
        if (dish.getCalories() <= 400)
            return CaloricLevel.DIET;
        else if (dish.getCalories() <= 700)
            return CaloricLevel.NORMAL;
        else return CaloricLevel.FAT;
    }));
```
filtering

```java
Map<String, List<Dish>> caloricDishesByType = menu.stream()
    .collect(Collectors.groupingBy(Dish::getType,
        Collectors.filtering(dish -> dish.getCalories() > 500,
        Collectors.toList())));
```

Result:

```
{OTHER=[french fries, pizza],
  MEAT=[pork, beef],
  FISH=[]}
```

Note the empty group (unachievable with `filter`).
Collectors Grouping and Partitioning

```java
Map<String, List<String>> dishNamesByType = menu.stream()
    .collect(groupingBy(Dish::getType,
        mapping(Dish::getName, toList())));
```
Multilevel Grouping

Map<String, Map<CaloricLevel, List<Dish>>> res =
    menu.stream().collect(
        groupingBy(Dish::getType,
            groupingBy(dish -> {
                if (dish.getCalories() <= 400)
                    return CaloricLevel.DIET;
                else if (dish.getCalories() <= 700)
                    return CaloricLevel.NORMAL;
                else return CaloricLevel.FAT;
            })
    );
Collectors Grouping and Partitioning

**partitioningBy**

```java
Map<Boolean, List<Dish>> partitionedMenu = menu.stream()
    .collect(partitioningBy(Dish::isVegetarian));
```

- Always generate lists for both `true` and `false`.
- Special map optimized for two values.
Outline

Special Streams

Collectors

- collect
- Reducing and Summarizing
- Other Single-Level Collectors
- Grouping and Partitioning
- Custom Collector

Summary and References
Collector Interface

```java
public interface Collector<T, A, R> {
    Supplier<A> supplier();
    BiConsumer<A, T> accumulator();
    Function<A, R> finisher();
    BinaryOperator<A> combiner();
    Set<Characteristics> characteristics();
}
```

- **T** stream element
- **A** accumulator element (temporary/intermediate result)
- **R** final returned element

Example in the following slides: `toList (A and R are both List<T>).`
collect { (Diamond, [ ]) -> [Diamond] }
Supplier

Initial value for the accumulator:

```java
public Supplier<List<T>> supplier() {
    return ArrayList<T>::new;
}
```
Accumulator

Takes an element and merge it with the accumulator:

```java
public BiConsumer<List<T>, T> accumulator() {
    return List::add;
}
```
Convert the accumulator to the final result:

```java
public Function<List<T>, List<T>> finisher() {
    return Function.identity();
}
```
A accumulator = collector.supplier().get();

collector.accumulator().accept(accumulator, next)

Are there more items in the stream?

Yes

T next = fetch next stream's item

No

R result = collector.finisher().apply(accumulator);

return result;

End
Combiner

Combine two accumulators:

```java
public BinaryOperator<List<T>> combiner() {
    return (list1, list2) -> {
        list1.addAll(list2);
        return list1;
    }
}
```

- Allows the parallelization: each core processes a part of the stream, which leads to a set of accumulators that are combined.
Split the stream in 2 subparts

Split the stream in 2 subparts

Split the stream in 2 subparts

Keep dividing the stream until each subpart is small enough

Process each substream in parallel using the former sequential algorithm

R r1 = collector.combiner().apply(acc1, acc2);

R r2 = collector.combiner().apply(acc3, acc4);

A accumulator = collector.combiner().apply(r1, r2);

Combine the results of the independent processing of each substream

R result = collector.finisher().apply(accumulator);

return result;
Collectors Custom Collector

Characteristics

**UNORDERED** does not commit to preserve order

**CONCURRENT** can be parallelized (on all streams if UNORDERED, on unordered streams only otherwise)

**IDENTITY_FINISH** finisher is the identity function

```java
public Set<Characteristics> characteristics() {
    return Collections.unmodifiableSet(EnumSet.of(
        IDENTITY_FINISH, CONCURRENT));
}
```
Alternative

```java
List<Dish> dishes = menuStream
    .collect(ArrayList<Dish>::new,
             List::add,
             List::addAll);
```
<table>
<thead>
<tr>
<th>Collector</th>
<th>argument</th>
<th>chaining</th>
</tr>
</thead>
<tbody>
<tr>
<td>toList/toSet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>minBy/maxBy</td>
<td>Comparator</td>
<td></td>
</tr>
<tr>
<td>summingInt</td>
<td>keyExtractor</td>
<td></td>
</tr>
<tr>
<td>averagingInt</td>
<td>keyExtractor</td>
<td></td>
</tr>
<tr>
<td>summarizingInt</td>
<td>keyExtractor</td>
<td></td>
</tr>
<tr>
<td>counting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>reducing</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>joining</td>
<td>String</td>
<td></td>
</tr>
<tr>
<td>filtering</td>
<td>Predicate</td>
<td>✓</td>
</tr>
<tr>
<td>mapping</td>
<td>Function</td>
<td>✓</td>
</tr>
<tr>
<td>flatMapping</td>
<td>Function</td>
<td>✓</td>
</tr>
<tr>
<td>collectingAndThen</td>
<td>Function</td>
<td>✓</td>
</tr>
<tr>
<td>groupingBy</td>
<td>Function</td>
<td>✓</td>
</tr>
<tr>
<td>partitioningBy</td>
<td>Predicate</td>
<td>✓</td>
</tr>
</tbody>
</table>
Outline

Special Streams

Collectors

Summary and References
Official Documentation

- Documentation of interface Collector
- Documentation of class Collectors
Demonstration

Compute the sum of all numbers between 1 and $n$ which square is below 20:

```java
IntStream.rangeClosed(1, n)
    .filter(i -> i * i < 20)
    .sum()
```
Special Streams

- Primitive specializations of streams: `IntStream`, `DoubleStream`, and `LongStream`.
- Other sources: from values, arrays, files, etc.
- Infinite stream: `iterate` and `generate` with short-circuiting.
Collectors

- `collect` accumulates the elements of a stream into a summary result.
- Collectors compose to create multilevel groupings, partitions, and reductions (`groupingBy`, `partitioningBy`, etc.).
- Custom collectors must implement the methods defined in the `Collector` interface.