Multicore Programming
Java Streams

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

Bureau 414C

Master 1 computer science – Semester 8
Motivations

- Express simple iterations in a declarative way without writing the loop logic.
- Simple way to parallelize without writing the thread logic.
- Java Streams introduced in Java 8 (2014, LTS, support until 2025).
- Called *iterators* in Rust.
Outline

Concepts

Stream Operations

Summary and References
Outline

Concepts

Stream Definition

Streams vs. Collections
Intermediates and Terminal Operations

Stream Operations

Summary and References
Example without Streams

```java
List<Dish> highCal = new ArrayList<>();
for (Dish dish: menu)
    if (dish.getCalories() > 300)
        highCal.add(dish);
List<String> highCalName = new ArrayList<>();
for (Dish dish: highCal)
    lowCalName.add(dish.getName());
lowCalName = highCalName.subList(0, 3);
```
Example with Streams

```java
List<String> highCalName =
    menu.stream()
    .filter(d -> d.getCalories() > 300)
    .map(Dish::getName)
    .limit(3)
    .toList();
```
menu → lambda → filter → lambda → map → integer → limit → toList()
Menu stream

\[ \text{filter}(d \rightarrow d\.getCalories() > 300) \]

\[ \text{map}(\text{Dish}::\text{name}) \]

\[ \text{limit}(3) \]

\[ \text{toList}() \]

Stream\langle\text{Dish}\rangle

Stream\langle\text{Dish}\rangle

Stream\langle\text{String}\rangle

Stream\langle\text{String}\rangle

List\langle\text{String}\rangle
Benefits

- declarative (no flow control): readable and concise
- composable/flexible/extensible: easy to modify
- parallelizable
A stream is a sequence of elements coming from a source and that supports data-processing operations.

- **sequence of elements** interface to access a sequenced set of values (not necessarily sorted)
- **source** data are provided by a collection, array or I/O resource
- **data-processing operations** support for database-like or functional operations
Characteristics

Pipelining stream operation may return a stream
Internal iteration iteration (loop logic) is implicit
Outline

Concepts

Stream Definition

Streams vs. Collections

Intermediate and Terminal Operations

Stream Operations

Summary and References
Similarity between Streams and Collections

- Iteration on a sequenced set of values.
Differences

- Lazy vs. Eager Evaluation: values are only computed as needed.
- Traversable only once: a stream cannot be consumed multiple times.
- Internal vs. external iterations: iterations can be transparently done in parallel or in a different more optimized order.
Outline

Concepts
- Stream Definition
- Streams vs. Collections
- Intermediate and Terminal Operations

Stream Operations

Summary and References
menu \rightarrow \text{filter} \rightarrow \text{map} \rightarrow \text{limit} \rightarrow \text{toList()}

Intermediate operations

Terminal operation
Intermediate Operations

Intermediate operations:

- return another stream
- only define processing operations that will be performed (lazy evaluation)
Example

```java
List<String> names = menu.stream()
    .filter(dish -> {
        System.out.println("filtering:" + dish.getName());
        return dish.getCalories() > 300;
    })
    .peek(dish -> System.out.println("mapping:" + dish.getName()))
    .map(Dish::getName)
    .limit(3)
    .toList();
```
Example Output

Example with 10 dishes in menu:

filtering: salad
filtering: pork
mapping: pork
filtering: beef
mapping: beef
filtering: chicken
mapping: chicken
Terminal Operations

Terminal operations produce a result from a stream pipeline (lazy evaluation).
Summary

▶ A data source (such as a collection) to perform a query on.
▶ A chain of intermediate operations that forms a stream pipeline.
▶ A terminal operation that executes the stream pipeline and produces a result.
Outline

Concepts

Stream Operations
  Filtering
  Slicing
  Mapping
  Finding and Matching
  Reducing

Summary and References
Equivalences:

▶ (a, b) -> a + b
▶ (int a, int b) -> a + b
▶ (int a, int b) -> { return a + b; }
▶ Integer::sum

class Integer {
    public static int sum(int a, int b) {
        return a + b;
    }
}

Stream Operations

Java: Lambda Function and Method Reference
Java: Special Function Names

From package java.util.function:

- **Supplier** void -> T
- **Consumer** T -> void
- **Function** T -> R (for map)
- **UnaryOperator** T -> T
- **Predicate** T -> boolean (for filter)

Equivalences with different arity:

- **BiConsumer** (T, U) -> void
- **BiFunction** (T, U) -> R
- **BinaryOperator** (T, T) -> T (for reduce)
- **BiPredicate** (T, U) -> boolean
Outline

Concepts

Stream Operations
  Filtering
  Slicing
  Mapping
  Finding and Matching
  Reducing

Summary and References
Predicate

- A predicate is a function returning a boolean.
- Used to filter values.
Stream Operations Filtering

**filter**

Menu stream

\[ \text{filter} \text{(Dish::isVegetarian)} \]

\[ \text{toList()} \]

\[ \text{Stream\langle Dish\rangle} \]

\[ \text{List\langle Dish\rangle} \]
distinct

Numbers stream

1 2 1 3 3 2 4

Stream<Integer>

filter(i -> i % 2 == 0)

2 2 4

Stream<Integer>

distinct()

2 4

Stream<Integer>
Outline

Concepts

Stream Operations
  Filtering
  Slicing
  Mapping
  Finding and Matching
  Reducing

Summary and References
Definition

- Slicing: skip elements by ignoring either first or last elements.
- With a fixed number of elements: limit, skip.
- With a predicate (from Java 9): takeWhile, dropWhile.
**limit**

Menu stream

\[
\text{filter}(d \to d\text{.getCalories}() > 300)
\]

\[
\text{limit}(2)
\]

\[
\text{collect}(\text{toList}())
\]
skip

Menu stream

filter(d -> d.getCalories() > 300)

skip(1)

collect(toList())
skip(1)
**takeWhile**

```java
List<Dish> slicedMenu = specialMenu.stream()
   .takeWhile(dish -> dish.getCalories() < 320)
   .toList();
```

- The methods `takeWhile` and `dropWhile` are more efficient than a filter when you know that the source is sorted.
takeWhile(≠)
Outline

Concepts

Stream Operations
  Filtering
  Slicing
  Mapping
  Finding and Matching
  Reducing

Summary and References
map

Applying a function:

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

Types:

1. `menu`: `List<Dish>`
2. `menu.stream()`: `Stream<Dish>`
3. `menu.stream().map(...)`: `Stream<String>`
4. `menu.stream().map(...).toList()`: `List<String>`
map \{\textcircled{•} - \rightarrow \text{□}\}
flatMap

Flattening streams:

```java
List<String> uniqueCharacters =
    words.stream()
    .map(s -> s.split(""))
    .flatMap(Arrays::stream)
    .distinct()
    .toList();
```

- Apply a function that returns a stream (as map).
- Merge the resulting streams into a single one.
Stream of words

map(s -> s.split(""))

flatMap(Octets::stream)

distinct()

collect(toList())
Difference between `map` and `flatMap`

Types:

1. `words`: `List<String>`
2. `words.stream()`: `Stream<String>`
3. `words.stream().map(s -> s.split(""))`: `Stream<String[]>`
4. `Arrays::stream`: `String[] -> Stream<String>`
5. `words.stream().map(s -> s.split("")).map(Arrays::stream)`: `Stream<Stream<String>>`
Outline

Concepts

Stream Operations
  Filtering
  Slicing
  Mapping
  Finding and Matching
  Reducing

Summary and References
Matching: anyMatch, allMatch, noneMatch

Rely on a predicate:

```java
boolean isHealthy = menu.stream()
    .allMatch(dish -> dish.getCalories() < 1000);

boolean isHealthy = menu.stream()
    .noneMatch(d -> d.getCalories() >= 1000);
```
`allMatch()`
Short-Circuiting

- Interrupt the processing iteration on the stream as soon as a condition is met.
- Similar to evaluation mechanism with \( \| \) and \( \&\& \).
- Equivalent to a break in a loop.
- Apply to \texttt{limit} and \texttt{takeWhile} as well.
- Allow infinite stream.
Finding: `findAny`, `findFirst`

```java
Optional<Dish> dish = menu.stream()
    .filter(Dish::isVegetarian)
    .findAny();
```

- `findAny` is better for parallelization than `findFirst`
Java: `Optional<T>`

An object that is either defined or null (explicit management of null references).

```java
boolean isPresent()
ifPresent(Consumer<T> block)
T get()
T orElse(T other)
```
Outline

Concepts

Stream Operations
  Filtering
  Slicing
  Mapping
  Finding and Matching
  Reducing

Summary and References
Reducing a list of elements into a single value (also called *fold*):

```java
int sum = numbers.stream().reduce(0, (a, b) -> a + b);
```
Numbers stream

\textbf{reduce}(0, (a, b) \to a + b)

\begin{align*}
4 & \to 5 \\
\downarrow & \quad \downarrow \\
4 & \to 5 \\
\downarrow & \quad \downarrow \\
+ & \quad + \\
4 & \to 9 \\
\downarrow & \quad \downarrow \\
9 & \to 12 \\
\downarrow & \quad \downarrow \\
+ & \quad + \\
& \to 21
\end{align*}

\text{Stream}\langle\text{Integer}\rangle

Integer
No Initial Value

```java
Optional<Integer> product = numbers.stream()
    .reduce((a, b) -> (a * b));
```
Maximum and Minimum

```java
Optional<Integer> max = numbers.stream()
    .reduce(Integer::max);
Optional<Integer> min = numbers.stream()
    .reduce(Integer::min);
```
Stateless vs. Stateful

- `reduce` is stateful (with a bounded state), i.e. it keeps an intermediate result (called an *accumulator*).
- `sorted` and `distinct` are even more stateful (unbounded state): they need to buffer all the elements of the stream to proceed.
Can use the natural order or a custom comparison criterion.

```java
menu.stream()
  .sorted(comparing(Dish::getCalories))
  .toList();
```
A comparator is used to compare two objects.

A static helper function builds a comparator. It requires a function that extracts the key on which the objects must be compared to.

```java
int compare(T o1, T o2)
static Comparator<T> comparing(Function<T, Comparable> keyExtractor)
```
In addition to the distinction between intermediate and terminal operations, operations are characterized by whether they:

- allow short-circuiting
- return an optional (for terminal operations)
- are stateful (bounded or not)
<table>
<thead>
<tr>
<th>Operation</th>
<th>terminal stateful short-circuiting interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>filter</td>
<td>Predicate</td>
</tr>
<tr>
<td>map</td>
<td>Function</td>
</tr>
<tr>
<td>flatMap</td>
<td>Function*</td>
</tr>
<tr>
<td>sorted</td>
<td>Comparator</td>
</tr>
<tr>
<td>distinct</td>
<td></td>
</tr>
<tr>
<td>limit</td>
<td>long</td>
</tr>
<tr>
<td>skip</td>
<td>long</td>
</tr>
<tr>
<td>takeWhile</td>
<td>Predicate</td>
</tr>
<tr>
<td>dropWhile</td>
<td>Predicate</td>
</tr>
<tr>
<td>allMatch</td>
<td>Predicate</td>
</tr>
<tr>
<td>noneMatch</td>
<td>Predicate</td>
</tr>
<tr>
<td>anyMatch</td>
<td>Predicate</td>
</tr>
<tr>
<td>findAny</td>
<td></td>
</tr>
<tr>
<td>findFirst</td>
<td></td>
</tr>
<tr>
<td>reduce</td>
<td>BinaryOperator</td>
</tr>
<tr>
<td>toList</td>
<td></td>
</tr>
</tbody>
</table>
Outline

Concepts

Stream Operations

Summary and References
Official Documentation

- Documentation of package stream
- Documentation of interface Stream
- Tutoriel Java
Demonstration

Compute the list of all numbers between 1 and 5 which square is below 20:

```java
List<Integer> numbers = Arrays.asList(1, 2, 3, 4, 5);
numbers.stream()
    .filter(i -> i < 20)
    .peek(System.out::println)
    .toList();
```
Summary

- A stream is a sequence of elements from a source that supports data-processing operations.
- The iteration is abstracted away and computed on demand (“lazily”).
- Intermediate operations return a stream.
- Terminal operations return a result.
- Some operations use short-circuiting and some are stateless.