Multicore Programming
Java Streams

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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
    Intermediate 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 → filter → map → limit → toList()
Menu stream

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

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

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

\[ \text{toList()} \]
Benefits

- declarative (no flow control): readable and concise
- composable/flexible/extensible: easy to modify
- parallelizable
Definition

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 → filter → map → limit → toList()
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
Java: Lambda Function and Method Reference

Equivalences:

- \((a, b) \rightarrow a + b\)
- \((\text{int}\ a, \text{int}\ b) \rightarrow a + b\)
- \((\text{int}\ a, \text{int}\ b) \rightarrow \{ \text{return}\ a + b; \}\)
- \text{Integer::sum}

```java
class Integer {
    public static int sum(int a, int b) {
        return a + b;
    }
}
```
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`
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Summary and References
Predicate

- A predicate is a function returning a boolean.
- Used to filter values.
**filter**

Menu stream

```
filter(Dish::isVegetarian)
```

toList()
distinct

Numbers stream

1 2 1 3 3 2 4

\[ \text{filter}(i \rightarrow i \mod 2 == 0) \]

2 2 4

\[ \text{distinct()} \]

2 4

Stream<Integer>
distinct
Outline

Concepts

Stream Operations
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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

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

```
limit(2)
```

```
collect(toList())
```

```
List<Dish>
```
**skip**

Menu stream

$$\text{stream} \leftarrow \text{Stream}\langle\text{Dish}\rangle$$

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

$$\text{stream} \leftarrow \text{Stream}\langle\text{Dish}\rangle$$

**skip(1)**

$$\text{stream} \leftarrow \text{Stream}\langle\text{Dish}\rangle$$

$$\text{collect}(\text{toList()})$$

$$\text{List}\langle\text{Dish}\rangle$$
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(≠)
dropWhile( ≠ )
Outline

Concepts

Stream Operations
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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 \{ \text{□} \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(Arrays::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>>`
flatMap
Outline

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Stream Operations
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- Mapping
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- 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(○) → true
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 `limit` and `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

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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

\[ \text{reduce}(0, (a, b) \rightarrow a + b) \]

Stream\langle\text{Integer}\rangle

\[
\begin{align*}
0 & \rightarrow + \\
4 & \rightarrow + \\
5 & \rightarrow + \\
3 & \rightarrow + \\
9 & \rightarrow + \\
12 & \rightarrow + \\
21 & \rightarrow \text{Integer}
\end{align*}
\]
reactiveX

.reduce route

.reduce method
No Initial Value

```
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();
```
Java: Comparator<T>

- 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)
```
Summary

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)
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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.