Programming in Java – Streams

Paolo Vercesi

Technical Program Manager

Agenda

Record primer

Streams

Working with streams

Specialized streams & stream creation

Parallel streams

Record primer

Record

The record keyword defines classes designed to be data transfer objects also called data carriers

```
public record Dish(String name, boolean vegetarian, int calories, Type type) {

    public enum Type {MEAT, FISH, OTHER}

    @Override
    public String toString() {
        return name;
    }
}
```

Record classes automatically generate

- Immutable fields
- A canonical constructor
- An accessor method for each element
- The equals() method
- The hashCode() method
- The toString() method

To know more about records

A good compact reference

https://blogs.oracle.com/javamagazine/post/java-records-constructor-methods-inheritance

Streams

Exercise

```
public record Dish(String name, boolean vegetarian, int calories, Type type) {

    public enum Type {MEAT, FISH, OTHER}

    @Override
    public String toString() {
        return name;
    }
}
```

```
List<Dish> menu = List.of(
        new Dish("pork", false, 800, Type.MEAT),
        new Dish("beef", false, 700, Type.MEAT),
        new Dish("chicken", false, 400, Type.MEAT),
        new Dish("french fries", true, 530, Type.OTHER),
        new Dish("rice", true, 350, Type.OTHER),
        new Dish("season fruit", true, 120, Type.OTHER),
        new Dish("pizza", true, 550, Type.OTHER),
        new Dish("prawns", false, 300, Type.FISH),
        new Dish("salmon", false, 450, Type.FISH)
);
```

Given a list of Dishes, create the list of dishes with less than 400 calories and sort them by the number of calories

The “imperative” solution - How

Explicit iterations

```
List<Dish> lowCaloricDishes = new ArrayList<>();
for (Dish dish : menu) {
    if (dish.calories() < 400) {
        lowCaloricDishes.add(dish);
    }
}

lowCaloricDishes.sort(Comparator.comparingInt(Dish::calories));

List<String> lowCaloricDishesName = new ArrayList<>();
for (Dish dish : lowCaloricDishes) {
    lowCaloricDishesName.add(dish.name());
}
```

Intermediate data

```
[season fruit, prawns, rice]
```

We provide the solution by mixing the logic to solve the problem with explicit iterations and intermediate data

The “declarative” solution - What

SELECT name FROM dish WHERE calories < 400 ORDER BY calories

```
List<String> lowCaloricDishesName = menu.stream()
                .filter(d -> d.calories() < 400)
                .sorted(Comparator.comparing(Dish::calories))
                .map(Dish::name)
                .toList();
```

```
[season fruit, prawns, rice]
```

The last operator decides the return type of the method chain

With streams, we make a continuous use of lambdas and method references,
even if lambdas and method references are not part of that API!

Imperative vs declarative

Imperative you focus on writing
how to obtain what you want

```
List<Dish> lowCaloricDishes = new ArrayList<>();
for (Dish dish : menu) {
    if (dish.calories() < 400) {
        lowCaloricDishes.add(dish);
    }
}

lowCaloricDishes.sort(Comparator.comparingInt(Dish::calories));

List<String> lowCaloricDishesName = new ArrayList<>();
for (Dish dish : lowCaloricDishes) {
    lowCaloricDishesName.add(dish.name());
}
```

Declarative you focus on declaring
what you want

```
List<String> lowCaloricDishesName = menu.stream()
    .filter(d -> d.calories() < 400)
    .sorted(Comparator.comparing(Dish::calories))
    .map(Dish::name)
    .toList();
```

This is not coming for free; the declarative approach needs higher level abstractions provided by the Stream API that introduce an internal DSL (Domain Specific Language) on top of Java

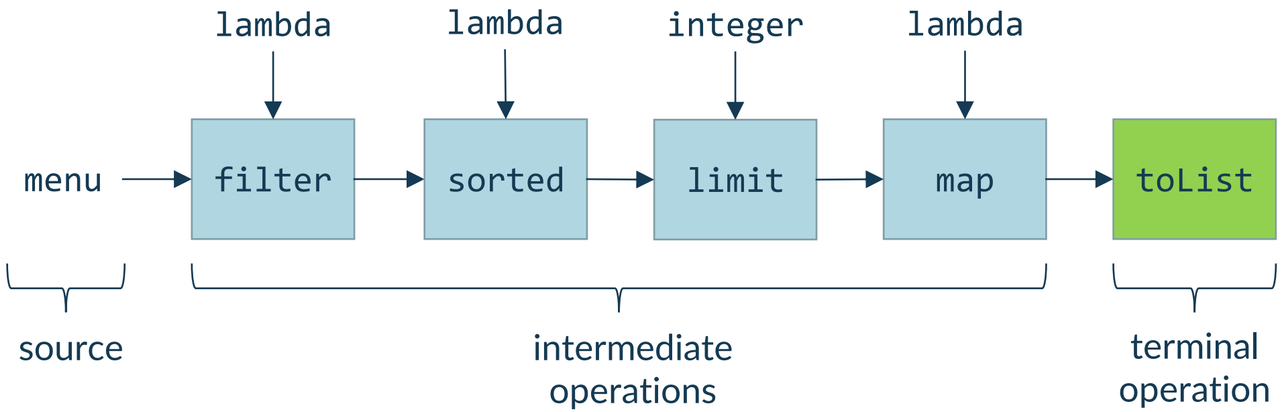
In other areas of the Java language, you don't have such kind of abstractions and maybe you can create them by yourself

Stream operations

Streams are used to perform computations made of operations composed into stream pipelines

A stream pipeline consists of

- a source, that might be an array, a collection, a generator function, an I/O channel, ...
- a chain of zero or more intermediate operations, transforming a stream into another stream
- a terminal operation, producing a result or a side-effect, e.g., count() or forEach(Consumer)




```
List<String> firstFiveLowCalories = menu.stream()
  .filter(d -> d.calories() < 400)
  .sorted(Comparator.comparing(Dish::calories))
  .limit(5)
  .map(Dish::name)
  .toList();
```

The result type depends on the only terminal operation

Streams are lazy, computation on the source data is only performed when the terminal operation is initiated, and source elements are consumed only as needed

Streams cannot be reused, you can pipeline just one intermediate or final operation

Streams

A sequence of elements from a source,
that supports data-processing operations

Some intermediate & terminal operators

Operation	Type	Return type	Argument of the operation	Function descriptor
`filter`	Intermediate	`Stream<T>`	`Predicate<T>`	`T -> boolean`
`map`	Intermediate	`Stream<R>`	`Function<T, R>`	`T -> R`
`limit`	Intermediate	`Stream<T>`	`int`	
`skip`	Intermediate	`Stream<T>`	`int`	
`sorted`	Intermediate	`Stream<T>`	`Comparator<T>`	`(T, T) -> int`
`distinct`	Intermediate	`Stream<T>`		
`forEach`	Terminal	`void`	`Consumer<T>`	`T -> void`
`count`	Terminal	`long`		
`toList`	Terminal	`List<T>`		
`collect`	Terminal	(generic)	`Collector<T, A, R>`	not a functional interface

Working with streams

Intermediate & terminal operations

Intermediate operations

Filtering
- selecting elements with predicate
- selecting unique elements

Sorting

Slicing
- slicing using a predicate
- truncating a stream
- skipping a stream

Mapping
- transform each element
- flattening streams

Peeking

Terminal operations

Counting elements

Consuming

Matching
- anyMatch, allMatch, noneMatch

Finding
- findAny, findFirst

Reducing

Collecting

Grouping

Partitioning

Intermediate operations

Filtering with filter() and distinct()

Selecting elements by using a predicate

```
List<Dish> vegetarianMenu = menu.stream()
        .filter(Dish::vegetarian)
        .toList();
```

Predicate taking a Dish and returning a boolean

Selecting unique elements

```
List<Integer> numbers = Arrays.asList(1, 2, 1, 3, 3, 2, 4);
numbers.stream()
        .filter(i -> i % 2 == 0)
        .distinct()
        .forEach(System.out::println);
```

Remove duplicates accordingly to hashcode() and equals()

Sorting

```
List<String> cities = List.of("Trieste", "Gorizia", "Udine", "Pordenone");
cities.stream()
        .sorted()
        .forEach(System.out::println);
```

Sorting based on the natural order of a Comparable class

Sorting based on a custom Comparator

```
List<Dish> menu = Dish.menu;
menu.stream()
        .sorted(Comparator.comparing(Dish::calories))
        .forEach(System.out::println);
```

Conditional slicing with takeWhile() and dropWhile()

```
List<Dish> specialMenu = Arrays.asList(
    new Dish("seasonal fruit", true, 120, Type.OTHER),
    new Dish("prawns", false, 300, Type.FISH),
    new Dish("rice", true, 350, Type.OTHER),
    new Dish("chicken", false, 400, Type.MEAT),
    new Dish("french fries", true, 530, Type.OTHER));
```

Select dished with less than 320 calories

```
List<Dish> filteredMenu = specialMenu.stream()
        .takeWhile(dish -> dish.calories() < 320)
        .toList();
```

Select dished with more than 320 calories

```
List<Dish> filteredMenu = specialMenu.stream()
        .dropWhile(dish -> dish.calories() < 320)
        .toList();
```

Assume the stream is ordered by calories ascending

Unconditional slicing with limit() and skip()

```
List<Dish> specialMenu = Arrays.asList(
    new Dish("seasonal fruit", true, 120, Type.OTHER),
    new Dish("prawns", false, 300, Type.FISH),
    new Dish("rice", true, 350, Type.OTHER),
    new Dish("chicken", false, 400, Type.MEAT),
    new Dish("french fries", true, 530, Type.OTHER));
```

Select the first three dishes with less than 500 calories

```
List<Dish> filteredMenu = specialMenu.stream()
        .filter(dish -> dish.calories() < 500)
        .limit(3)
        .toList();
```

Stream size is limited to 3

Skip the first two dishes with more than 300 calories

```
List<Dish> filteredMenu = specialMenu.stream()
        .filter(dish -> dish.calories() > 300)
        .skip(2)
        .toList();
```

Skip the first two elements

Mapping

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

Map each dish to its name

```
[pork, beef, chicken, french fries, rice, season fruit, pizza, prawns, salmon]
```

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

Map each dish to its uppercase name

```
[PORK, BEEF, CHICKEN, FRENCH FRIES, RICE, SEASON FRUIT, PIZZA, PRAWNS, SALMON]
```

```
List<Integer> dishNameLengths = menu.stream()
        .map(Dish::name)
        .map(String::length)
        .toList();
```

Map each dish to its name length

```
[4, 4, 7, 12, 4, 12, 5, 6, 6]
```

Flattening streams

The flatMap operation is used when you need to transform the element of a stream into new streams and you want to flatten these new streams into a single stream

Example create a single stream from two streams

```
Stream.of(Stream.of(1, 2), Stream.of(3, 4))
    .flatMap(x -> x)
    .forEachOrdered(System.out::println);
```

Can be replaced by Function.identity

Example create a single stream from two lists

```
Stream.of(List.of(1, 2), List.of(3, 4))
    .flatMap(x -> x.stream())
    .forEachOrdered(System.out::println);
```

Usually, we use flatMap with a function that transform the current type into a Stream

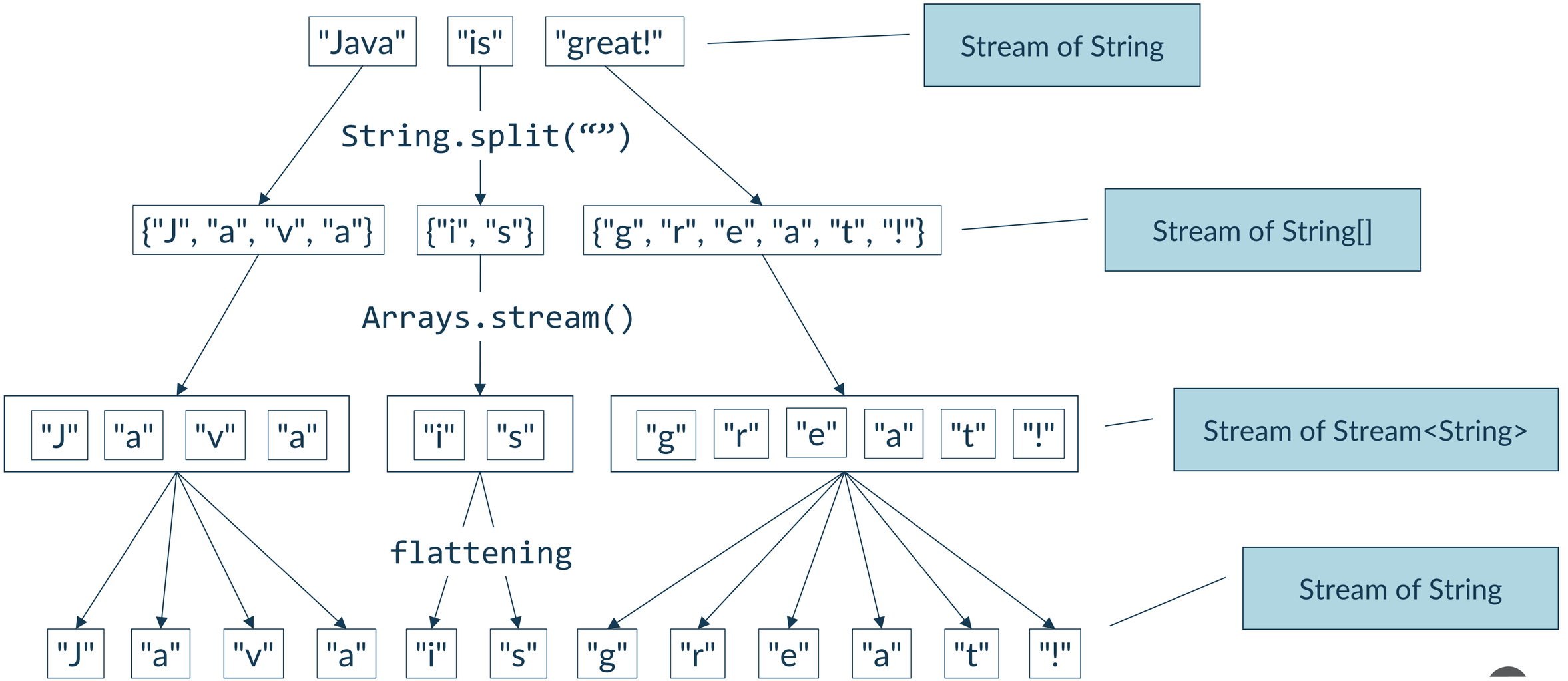
Flattening streams

Example: we have a list of strings and we want to create a list of unique characters contained in these strings

```
List<String> strings = List.of("Java", "is", "great!");
List<String> distinct = strings.stream()
        .map(s -> s.split(""))
        .flatMap(Arrays::stream)
        .distinct()
        .toList();
System.out.println(distinct);
```

```
[J, a, v, i, s, g, r, e, t, !]
```

Flattening streams



Cartesian product

Exercise: Given two lists of numbers, how would you return all pairs of numbers?
For example, given a list [1, 2, 3] and a list [3, 4] you should return [(1, 3), (1, 4), (2, 3), (2, 4), (3, 3), (3, 4)].

```
List<Integer> list1 = List.of(1, 2, 3); List<Integer> list2 = List.of(3, 4);
```

We start by traversing list1, then for each element of list1 we must traverse list2 and create a list with the two elements coming from the two streams

```
list1.stream().map(i1 -> list2.stream().map(i2 -> List.of(i1, i2)))
```

Stream<Stream<List<Integer>>>

We mapped i1 to a stream of couples of i1 with elements from list2, now we must flat this map

```
list1.stream()
        .map(i1 -> list2.stream().map(i2 -> List.of(i1, i2)))
        .flatMap(Function.identity())
        .toList()
```

Stream<List<Integer>>

or

```
list1.stream()
        .flatMap(i1 -> list2.stream().flatMap(i2 -> List.of(i1, i2))).toList()
```

peek()

```
Stream<T> peek(Consumer<? super T> action)
```

Returns the same stream after consuming the item,
it doesn't change the stream

```
Optional<Integer> value = Stream.of(1, 2, 3, 4)
        .peek(x -> System.out.println("processing: " + x))
        .filter(n -> n % 2 == 0)
        .peek(y -> System.out.println("accepted " + y))
        .findFirst();
```

only for debugging!

Terminal operations

Counting and consuming elements

Counting elements

```
Optional<Integer> value = Stream.of(1, 2, 3, 4)
        .filter(n -> n % 2 == 0)
        .count();
```

```
2
```

Consuming elements with forEach

```
Stream.of(1, 2, 3, 4)
        .filter(n -> n % 2 == 0)
        .forEach(System.out::println);
```

```
2
4
```

Matching

Is there at least one vegetarian dish?

```
boolean atLeastOneVegetarian = menu.stream()
    .anyMatch(Dish::vegetarian);
```

Is the menu vegetarian only?

```
boolean vegetarianOnly = menu.stream()
    .allMatch(Dish::vegetarian);
```

Are all dishes free from meat and fish?

```
boolean noMeatNoFish = menu.stream()
    .noneMatch(d -> d.type() == Type.MEAT || d.type() == Type.FISH);
```

Finding with findAny()

Find any vegetarian dish

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

The operation findAny() returns an Optional because it might not find any match

Find a vegetarian dish with meat

```
Optional<Dish> dish = menu.stream()
        .filter(Dish::vegetarian)
        .filter(d -> d.type() == Type.MEAT)
        .findAny();
```

The Optional<T> class to model the fact that a method call can return something that does not exists

Working with Optional

```
Optional<String> optionalName = menu.stream()
        .filter(Dish::vegetarian)
        .map(Dish::name)
        .findAny();

if (optionalName.isPresent()) {
    System.out.println(optionalName.get());
}
```

Imperative style, get the value out of the Optional by using isPresent() and get() and do some if-programming

Never use get() unless you have checked if the value isPresent()

```
menu.stream()
        .filter(Dish::vegetarian)
        .map(Dish::name)
        .findAny()
        .ifPresent(name -> System.out.println(name));
```

Declarative (functional) style, ask the optional to do something by using ifPresent(Consumer<T> action)

The API of Optional contains many other methods for functional style programming

```
public T get() throws NoSuchElementException

public boolean isPresent()

public void ifPresent(Consumer<? super T> action)
```

Digression - Using Optional as return value

If you have a method that can optionally return null, you can consider to return an Optional

Optional is a final class with a private constructor, to build an optional we use one of three provided factory methods

```
public static <T> Optional<T> ofNullable(T value)

public static <T> Optional<T> empty()

public static <T> Optional<T> of(T value) throws NullPointerException
```

There is no way to wrap a null value into an Optional object, an Optional can be empty but it cannot contain a null value

If a method declares to return Optional then you should never return null instead of an Optional

Finding with findFirst()

Find any vegetarian dish

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

Find the first vegetarian dish

```
Optional<Dish> dish = menu.stream()
        .filter(Dish::vegetarian)
        .findFirst();
```

Why we have both findAny() and findFirst()?

Some streams are said to be ordered because they have a defined encounter order

E.g., streams obtained from Lists or from a sort() intermediate operation do have an encounter order

When processing an ordered stream in parallel, findFirst() is more constraining than findAny()

ordered ⇔ encounter order ⇔ subject to ordering constraint

Reducing (folding)

Reducing is about combining the elements of a stream into a single value

To answer questions like

1. What's the sum of all the calories in the menu?
    - We need to sum up all the calories values
2. What's the highest calories dish in the menu?
    - We need to compare all the calories values

We need to introduce new terminal operations to reduce the stream into a single value by combining all the elements of a stream to compute that single value

So far, we have seen terminal operations that do not combine the elements of the stream, e.g., matchAll, matchNone, findAny, findFirst, etc.

In the functional programming jargon, we need a fold operation

To perform a reduction, we need an associative and stateless function that combines two values into a single one

A bifunction like (a,b) -> c
where a is the previous value, b is the current value and c is the result
If a,b, and c are all of the same type we need just a binary operator (e.g. +)

Reducing API

The Stream interface contains three methods to reduce the stream

```
Optional<T> reduce(BinaryOperator<T> accumulator)

T reduce(T identity, BinaryOperator<T> accumulator)

<U> U reduce(U identity, BiFunction<U,? super T,U> accumulator, BinaryOperator<U> combiner)
```

Reducing example 1/3

```
Optional<T> reduce(BinaryOperator<T> accumulator)
```

Find the highest calories dish

```
Optional<Integer> dish = menu.stream()
    .map(Dish::calories)
    .reduce((a, b) ->  a > b ? a : b)
```

Can we use a method reference?

```
Optional<Integer> dish = menu.stream()
    .map(Dish::calories)
    .reduce(Integer::max);
```

Sum up all the calories in the menu

```
Optional<Integer> sum = menu.stream()
    .map(Dish::calories)
    .reduce((a, b) -> a + b);
```

Can we use a method reference?

```
Optional<Integer> sum = menu.stream()
    .map(Dish::calories)
    .reduce(Integer::sum);
```

Why Optional?

Reducing example 2/3

```
T reduce(T identity, BinaryOperator<T> accumulator)
```

The identity value is used as initial value for the reduction process, so no optional is needed

The identity value is an identity for the accumulator function, so that accumulator.apply(indentity, identity) evaluates as the identity value

```
Integer calories = menu.stream()
    .map(Dish::calories)
    .reduce(0, Integer::sum);
```

Reducing example 3/3

```
<U> U reduce(U identity, BiFunction<U,? super T,U> accumulator, BinaryOperator<U> combiner)
```

The combiner is used to combine the values coming from parallel computations

The identity value is an identity for the combiner function, so combiner.apply(indentity, identity) returns the identity value

The accumulator takes the accumulated value, the current value and returns the new accumulated value

```
Integer calories = menu.stream()
    .reduce(0, (a, c) -> a + c.calories(), Integer::sum);
```

One more reducing example

We want to concatenate strings by separating them by a comma

```
List<String> cities = Arrays.asList("Trieste", "Gorizia", "Udine", "Pordenone");
String reduced1 = cities.stream().reduce("", (x, y) -> x + ", " + y);
System.out.println(reduced1);
```

```
, Trieste, Gorizia, Udine, Pordenone
```

The provided indentity IS NOT an indentity for the accumulator function

```
Optional<String> reduced2 = cities.stream().reduce((x, y) -> x + ", " + y);
reduced2.ifPresent(System.out::println);
```

```
Trieste, Gorizia, Udine, Pordenone
```

Collecting

Collecting is a reduction operation that accumulates elements into a “mutable” container

```
<R> R collect(Supplier<R> supplier, BiConsumer<R,? super T> accumulator, BiConsumer<R,R> combiner)
```

Provides the mutable container of type R

Accumulates the elements of type T into the mutable container of type R

Combines the elements from intermediate container of type R

```
List<String> dishNames = menu.stream()
        .map(Dish::name)
        .collect(ArrayList::new, ArrayList::add, ArrayList::addAll);
```

```
List<String> dishNames = menu.stream()
        .collect(ArrayList::new, (a, d) -> a.add(d.name()), ArrayList::addAll);
```

Collecting using a Collector

```
<R,A> R collect(Collector<? super T,A,R> collector)
```

```
public interface Collector<T, A, R> {

    Supplier<A> supplier();

    BiConsumer<A, T> accumulator();

    BinaryOperator<A> combiner();

    Function<A, R> finisher();

    …
}
```

A function that creates and returns a new mutable result container

A function that folds a value into a mutable result container

A function that accepts two partial results and merges them, the combiner function may fold state from one argument into the other and return that, or may return a new result container

A function which transforms the intermediate result to the final result, e.g. to return an unmodifiable collection

The Collectors utility class provides lots of static methods to conveniently create an instance of the most common collectors

Collecting using Collectors, toList(), and toArray()

```
List<String> dishNames = menu.stream()
        .map(Dish::name)
        .collect(Collectors.toList());

List<String> dishNames = menu.stream()
        .map(Dish::name)
        .collect(Collectors.toUnmodifiableList());

Map<String, Dish> nameDishMap = menu.stream()
        .collect(Collectors.toMap(Dish::name, Function.identity()));
```

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

String[] dishNames = menu.stream()
        .map(Dish::name)
        .toArray();
```

Joining Strings

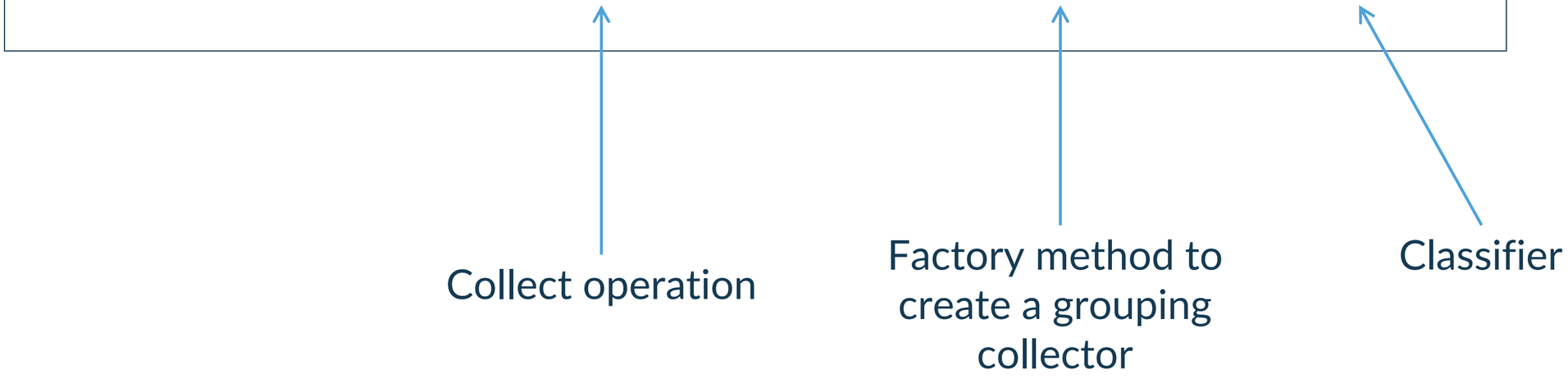
```
String result = menu.stream()
        .map(Dish::name)
        .map(name -> name.split(""))
        .flatMap(Arrays::stream)
        .distinct()
        .collect(Collectors.joining(", "));

System.out.println(result);
```

```
p, o, r, k, b, e, f, c, h, i, n,  , s, a, u, t, z, w, l, m
```

Grouping

In the collect() operation we can specify a grouping operation
to classify the element of the stream in different groups

```
Map<Type, List<Dish>> dishesByType =
        menu.stream().collect(Collectors.groupingBy(Dish::type));
```

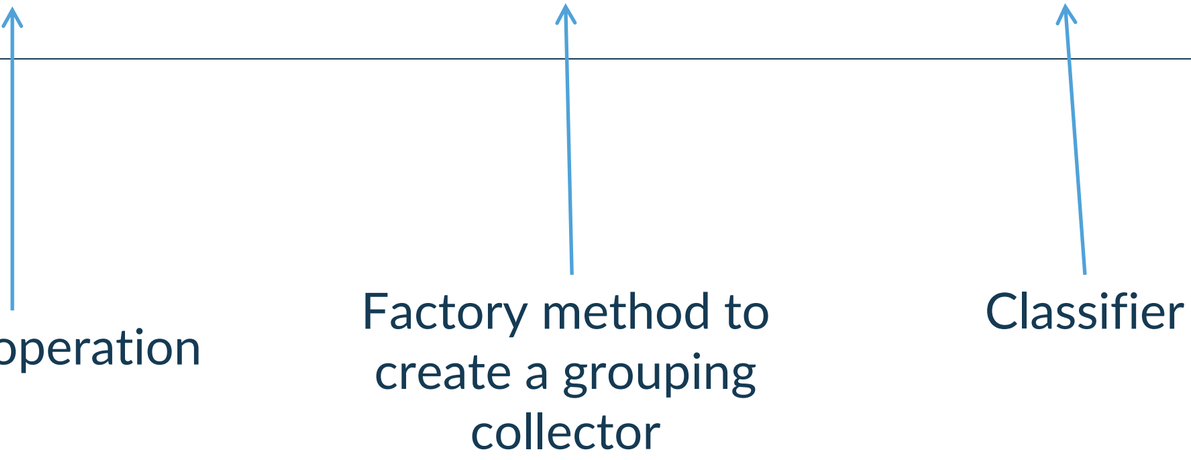



```
{FISH=[prawns, salmon], OTHER=[french fries, rice, season fruit,
pizza], MEAT=[pork, beef, chicken]}
```

Partitioning

Partitioning is a special case of grouping, that have a predicate called a partitioning function as a classification function

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




```
{false=[pork, beef, chicken, prawns, salmon],
true=[french fries, rice, season fruit, pizza]}
```

Specialized streams and stream creation

Numeric streams

The Streams API provides primitive stream specializations that support specialized methods to work with streams of numbers, to make common numeric reductions more efficient

These specialized streams are IntStream, DoubleStream, and LongStream

We can move from object streams to primitive streams by using on of the mapToInt/Double/Long methods

```
IntStream intStream = menu.stream().mapToInt(Dish::getCalories);

OptionalInt maxCalories = intStream.max();
```

We can move from specialized primitive streams to Object streams by using the boxed method

```
Stream<Integer> integerStream = intStream.boxed();
```

or by using the mapToObj method

```
intStream.mapToObj(x -> new int[] {x, x*2})
```

Numeric streams reductions

OptionalDouble	average()
OptionalInt/OptionalDouble/OptionalLong	max()
OptionalInt/OptionalDouble/OptionalLong	min()
int/double/long	sum()
IntSummaryStatistics/ DoubleSummaryStatistics/ LongSummaryStatistics	summaryStatistics()

```
IntStream stream = IntStream.of(1, 2, 3, 5, 7, 11, 13, 17, 19);
IntSummaryStatistics statistics = stream.summaryStatistics();
System.out.println(statistics);
```

```
IntSummaryStatistics{count=9, sum=78, min=1, average=8,666667, max=19}
```

Building streams from arrays and collections

Methods in Collection interface

```
default Stream<E> parallelStream()
default Stream<E> stream()
```

```
List.of("SDM", 2022, 2023).stream();
```

Build a stream of Objects

Methods in Arrays class

```
static DoubleStream stream(double[] array)
static DoubleStream stream(double[] array, int startInclusive, int endExclusive)
static IntStream stream(int[] array)
static IntStream stream(int[] array, int startInclusive, int endExclusive)
static LongStream stream(long[] array)
static LongStream stream(long[] array, int startInclusive, int endExclusive)
static <T> Stream<T> stream(T[] array)
static <T> Stream<T> stream(T[] array, int startInclusive, int endExclusive)
```

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

Build an IntStream

Building streams by enumerating the elements

`Stream.empty()`
`Stream.of(T …)`
`Stream.ofNullable(T t)`
	`Stream.of("Java", "is", "great!");`
	`Stream.of(null, new Object(), List.of("Java"));`
	`IntStream.of(2, 3, 5, 7, 11);`
	`DoubleStream.of(3.14, 6.28, 9.42);`

`Stream.builder()`	`Builder<String> b = Stream.builder();`
	`b.add("Java");`
	`b.add("is");`
	`b.add("great!");`
	`Stream<String> s = b.build();`

`Stream.concat(`
`  Stream<? extends T> a,`
`  Stream<? extends T> b)`
	`Stream<String> a = Stream.of("Java", "is", "great!");`
	`Stream<String> b = Stream.of("Hello", "World!");`
	`Stream<String> c = Stream.concat(a, b);`

`Int/LongStream.range(`
`  startInclusive,`
`  endExclusive)`
`Int/LongStream.rangeClosed(`
`  startInclusive,`
`  endInclusive)`
	`IntStream.range(0, 100);`
	`[0, 1, 2, …, 99]`
	`IntStream.rangeClosed(0, 99);`
	`[0, 1, 2, …, 99]`

Building infinite streams

Java provides three methods to generate infinite streams

```
static <T> Stream<T> generate(Supplier<? extends T> s)

static <T> Stream<T> iterate(T seed, UnaryOperator<T> f)

static <T> Stream<T> iterate(T seed, Predicate<? super T> hasNext, UnaryOperator<T> next)
```

This part of the stream API is used to generate data rather than to process data

```
DoubleStream randomGenerator = DoubleStream.generate(Math::random);
double[] randomNumbers = randomGenerator
        .limit(100)
        .toArray();
```

We can limit the generated data by using limit(int) or takeWhile(Predicate)

There are no other ways to stop the stream, but throwing an unchecked exception

Fibonacci

```
Stream.iterate(new int[] {0, 1}, a -> new int[] { a[1], a[0]+ a[1]})
        .limit(10)
        .map(a -> a[0])
        .forEach(System.out::println);
```

Generates the first ten Fibonacci numbers

```
Stream.iterate(new int[] {0, 1}, a -> new int[] { a[1], a[0]+ a[1]})
        .map(a -> a[0])
        .takeWhile(a -> a < 100)
        .forEach(System.out::println);
```

Generates Fibonacci numbers smaller than 100

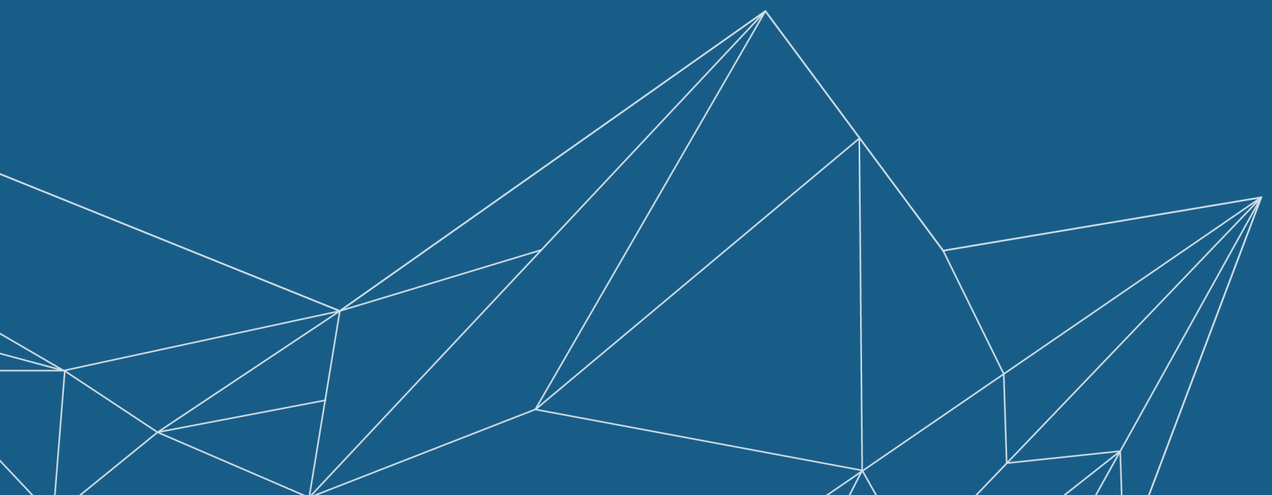
```
Stream.iterate(new int[] {0, 1}, a -> a[0] < 100, a -> new int[] { a[1], a[0]+ a[1]})
        .map(a -> a[0])
        .forEach(System.out::println);
```

Exercise: rewrite the iteration by using a for loop

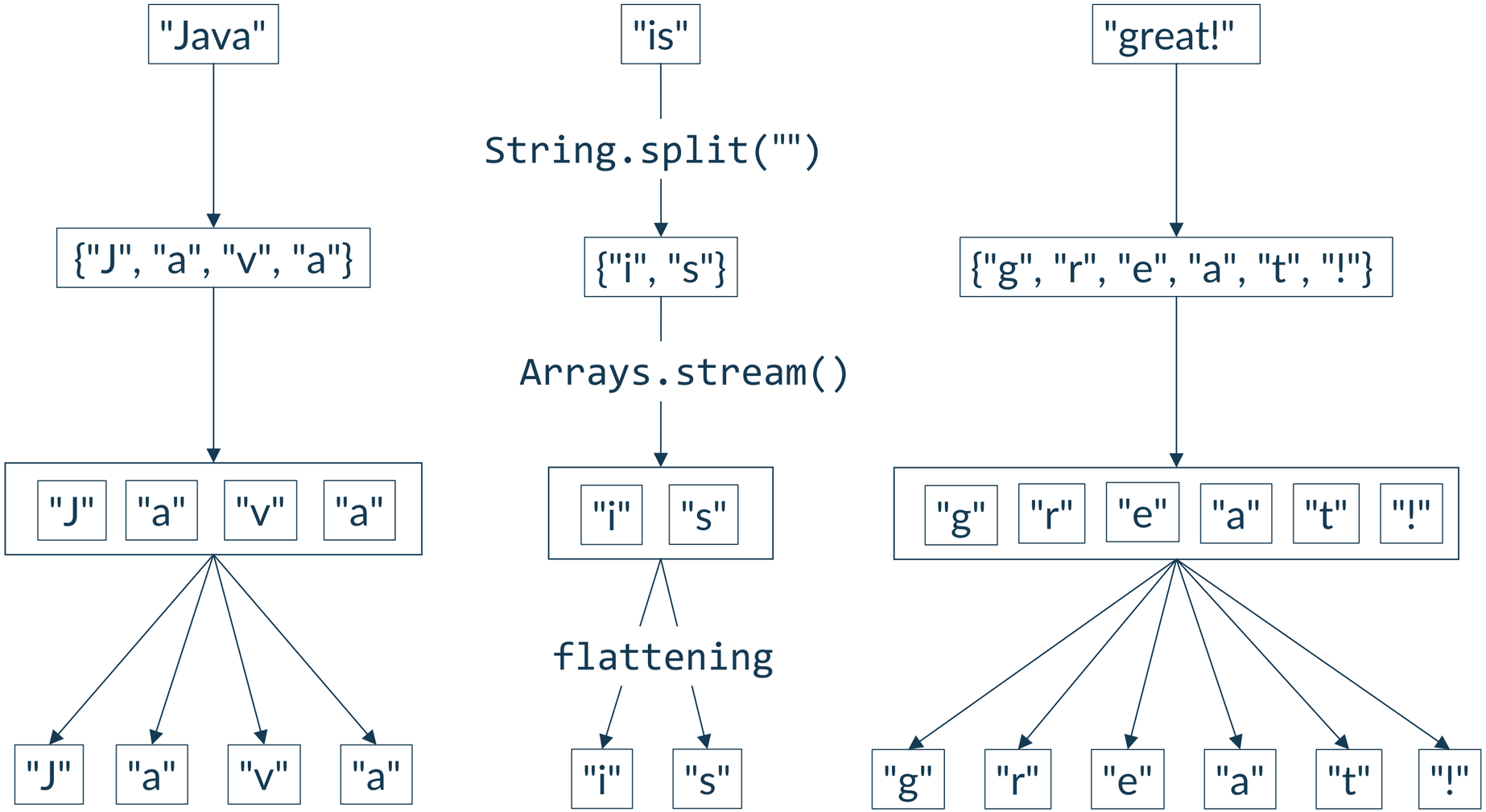
In principle, you can replace any for loop with a stream iteration
(if you don't mutate variables outside the for loop)

Is there any benefit in using streams over for/while/foreach loops?

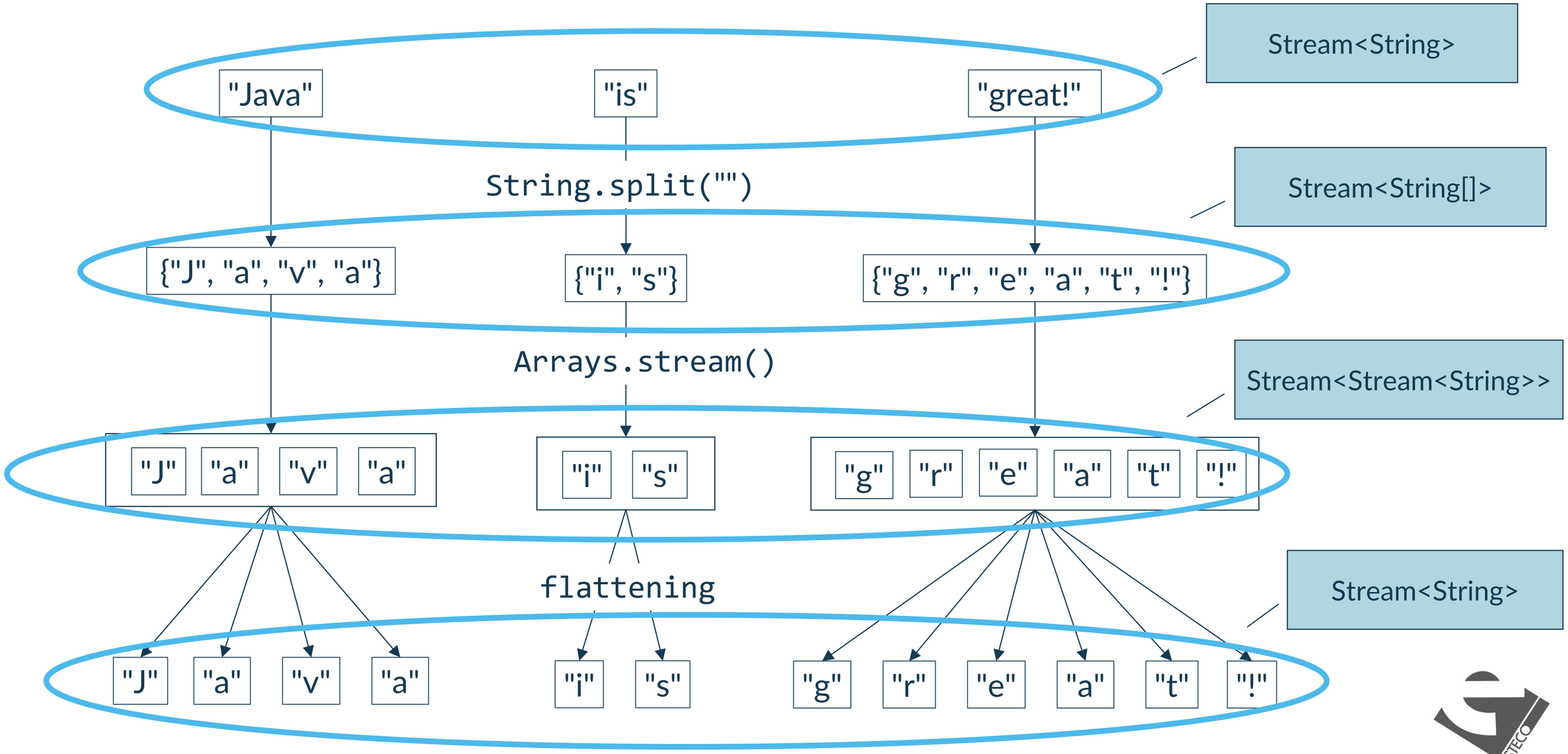
Parallel streams



Parallel data processing



Parallel data processing



Parallel execution of a Stream

```
List<String> strings = List.of("Java", "is", "great!");
List<String> distinct = strings.stream()
        .map(s -> s.split(""))
        .parallel()
        .flatMap(Arrays::stream)
        .distinct()
        .toList();
System.out.println(distinct);
```

Sequential and parallel stream processing

A stream has just one execution mode that can be parallel or sequential

```
List<String> strings = List.of("Java", "is", "great!");
List<String> distinct = strings.stream()
        .map(s -> s.split(""))
        .parallel()
        .flatMap(Arrays::stream)
        .sequential()
        .distinct()
        .toList();
System.out.println(distinct);
```

The position of the parallel() or sequential() method in the pipeline is irrelevant

It is not possible to specify which operations must be performed in parallel and which sequentially

If there are more parallel() and sequential() method invocations in the pipeline, the last one sets the execution mode

Ordered and unordered streams

Some stream sources are naturally ordered and they define an encounter order (ordering constraint) for the elements of the stream, e.g., arrays, lists, etc.

Some operations process the stream elements by following that encounter order, e.g., forEachOrdered(), findFirst()

Processing the stream under the ordering constraint imposes a significant penalty for the parallel processing, this penalty is not relevant for sequential processing

It possible to reset the stream to an unordered state by invoking unordered()

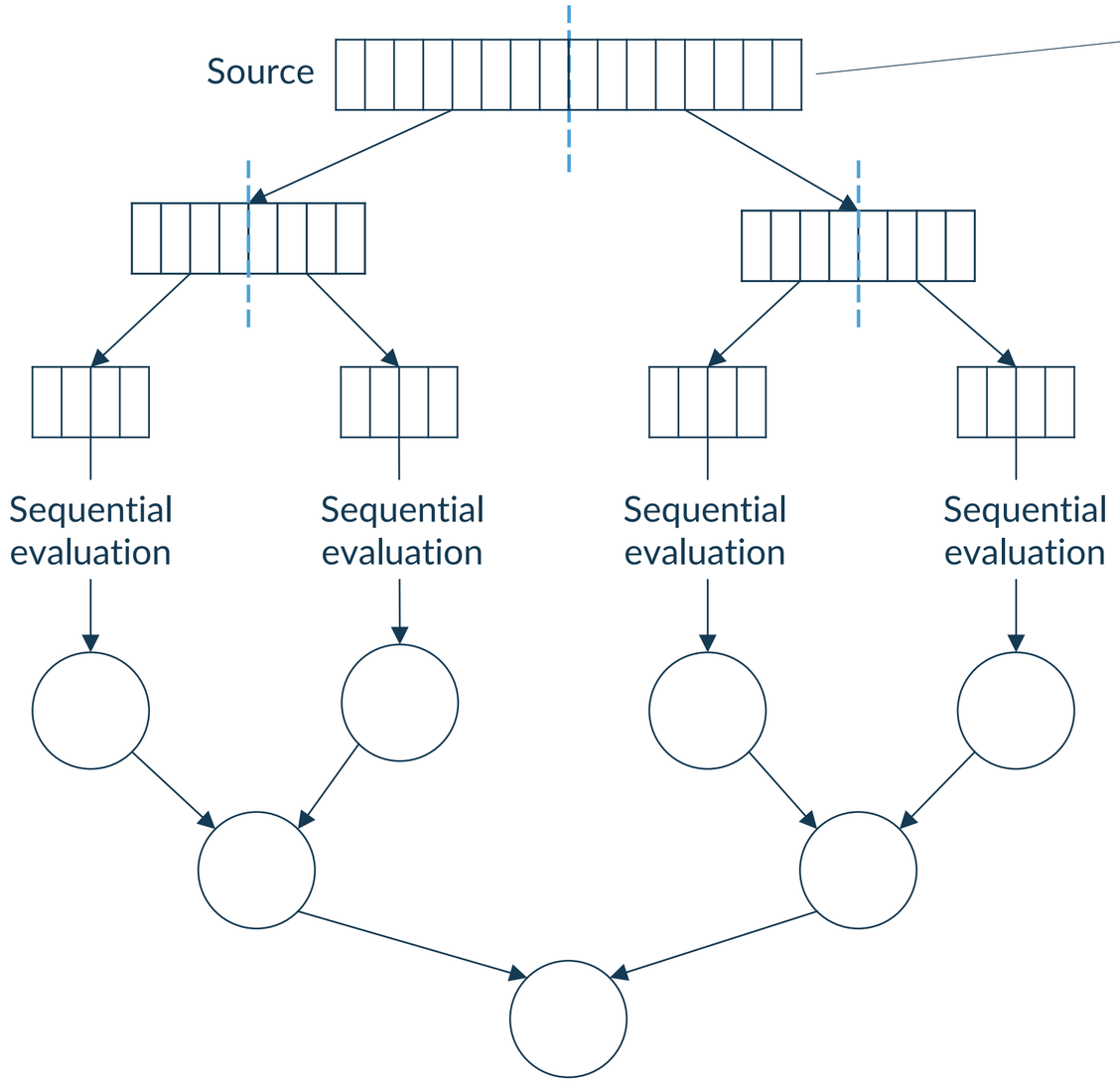
```
List<String> strings = List.of("Java", "is", "great!");
List<String> distinct = strings.stream()
        .map(s -> s.split(""))
        .flatMap(Arrays::stream)
        .parallel()
        .unordered()
        .distinct()
        .toList();
System.out.println(distinct);
```

The ordering constraint is set also by the sorted() operation on otherwise unordered streams

Using parallel and sequential effectively

- It is not possible to give a rule on when to use parallel or not
  - size of data set, cost of the processing
  - hardware, operating system, JVM settings, e.g., memory assigned to the JVM
- Always compare the performance of sequential and parallel with an appropriate benchmark
- Try to reduce the boxing/unboxing operations, use primitive stream when possible
- Operations which rely on ordering don't perform well on ordered streams in parallel
  - use alternatives findAny instead of findFirst
  - make the stream unordered
- Given N the size of the data set, Q the approximate cost of processing one element, and N*Q the total cost of the computation
  - higher Q can imply good performances in parallel
  - low N can imply bad performances in parallel
- Operations that are blocking on asynchronous calls, e.g., I/O operations, can take benefit from a different parallelization framework
- Consider the cost of the merging step of the terminal operation
- The source data stream can impact the effectiveness of parallelization, that is based on the fork/join framework

Fork/join and parallel streams



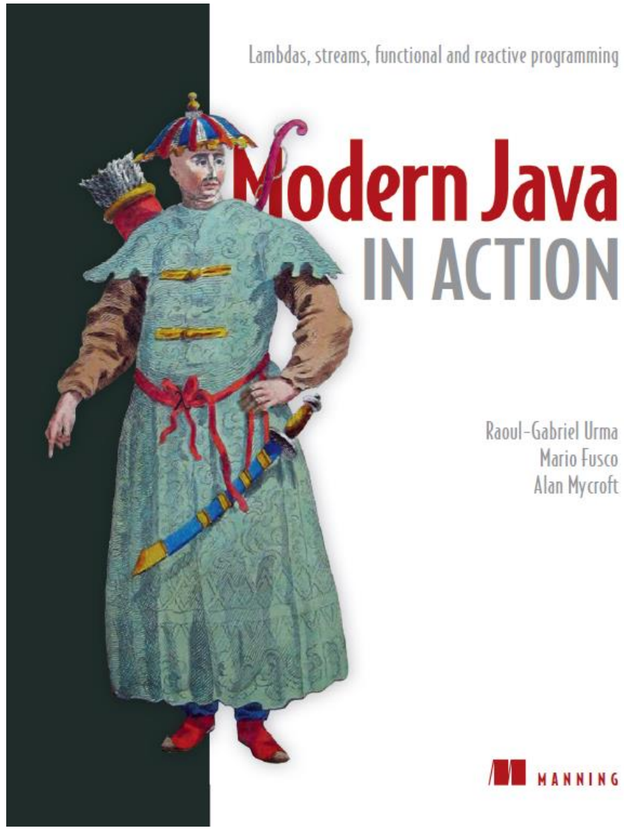
Stream parallelization starts to operate at the level of the data source

Source	Decomposability
`ArrayList`	Excellent
`IntStream.range`	Excellent
`HashSet`	Good
`TreeSet`	Good
`LinkedList`	Poor
`Stream.iterate`	Poor

Note: in this context the terms fork and join refers to forking and joining both data and processes

References

To know more



Raoul-Gabriel Urma, Mario Fusco, Alan Mycroft

Modern Java in Action

Thank you!

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