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JVA-074

Java Advanced I: Functional, Asynchronous and Reactive Programming

Module 1: Functional Java

Java Advanced I: Functional, Asynchronous and Reactive Programming

Subjects included in the course (35 hours):

1. Functional Java: functional interfaces, streams
2. Executor framework and Fork Join pool
3. NIO – non-blocking input/output
4. Asynchronous Java (Completable Future)
5. Reactive Streams (Java 9)
6. RxJava 2
7. R2DBC (reactive JDBC replacement)
8. Spring WebFlux (Reactor)
9. Reactive Spring Data JPA

Functional Interfaces
Method References

A Lambda Expression

Let's use an anonymous class

```
FileFilter fileFilter = new FileFilter() {
    @Override
    public boolean accept(File file) {
        return file.getName().endsWith(".java");
 }
};
```

We take the parameters and return:

```
FileFilter filter = (File file) -> file.getName().endsWith(".java");
```

This is a lambda expression.

Several Ways of Writing a Lambda Expression

The simplest way:

```
FileFilter filter = (File file) -> file.getName().endsWith(".java");
```

If you have more than one line of code:

```
Runnable r = () -> {
   for (int i = 0; i < 5; i++) {
      System.out.println("Hello world!");
   }
};
```

If you have more than one argument:

```
Comparator<String> c =
        (String s1, String s2) -> Integer.compare(s1.length(), s2.length());
```

What Is the Type of a Lambda Expression?

=> Functional interface

What is a functional interface?

A functional interface is one interface with **only one *abstract* method** (methods from class `Object` do not count)

```
public interface Runnable {
    run();
}

public interface Comparator<T> {
    int compareTo(T t1, T t2);
}

public interface FileFilter {
    boolean accept(File pathname);
}
```

Functional Interfaces

A functional interface can be annotated:

```
@FunctionalInterface
public interface MyFunctionalInterface {
    someMethod();
     /**
      * Some more documentation
     */
    equals(Object o);
};
```

The annotation is here just for convenience, as the compiler will tell me whether the interface is functional or not.

Functional Interfaces

Functional interface	Descriptor	Method name
Predicate<T>	T -> boolean	test()
BiPredicate<T, U>	(T, U) -> boolean	test()
Consumer<T>	T -> void	accept()
BiConsumer<T, U>	(T, U) -> void	accept()
Supplier<T>	() -> T	get()
Function<T, R>	T -> R	apply()
BiFunction<T, U, R>	(T, U) -> R	apply()
UnaryOperator<T>	T -> T	identity()
BinaryOperator<T>	(T, T) -> T	apply()

Examples:

```
Predicate<Integer> isAdult = age -> age >= 18;
isAdult.test(10);
Consumer<String> printer = p -> System.out.println("Printed: "+p);
printer.accept("hi");
Supplier<String> sayHi = () -> "hi";
sayHi.get(); // hi
```

Package java.util.function

Categories:

Supplier

```java
@FunctionalInterface
public interface Supplier<T> {
    T get();
}
```

Predicate

```java
@FunctionalInterface
public interface Predicate<T> {
    boolean test(T t);
}
```

Function

```java
@FunctionalInterface
public interface Function<T, R> {
    R apply(T t);
}
```

Consumer / BIConsumer

```java
@FunctionalInterface
public interface Consumer<T> {
    void accept(T t);
}

@FunctionalInterface
public interface BiConsumer<T, U> {
    void accept(T t, U u);
}
```

BIPredicate

```java
@FunctionalInterface
public interface BiPredicate<T, U> {
    boolean test(T t, U u);
}
```

Unary operator

```java
@FunctionalInterface
public interface UnaryOperator<T>
extends Function<T, T> {
}
```

Omitting Parameter

```
Comparator<String> c =
(String s1, String s2) -> Integer.compare(s1.length(), s2.length());
```

Becomes:

```
Comparator<String> c =
(s1, s2) -> Integer.compare(s1.length(), s2.length());
```

Method References

Example:
LambdaTest

```
Function<String, String> f = s -> s.toLowerCase();
```

Can be written like:

```
Function<String , String> f = String::toLowerCase;                f.apply("Hi") // hi
```

This lambda expression:

```
Consumer<String> c = s -> System.out.println(s);
```

Can be written like:

```
Consumer<String> c = System.out::println;
```

This lambda expression:

```
Comparator<Integer> c = (i1, i2) -> Integer.compare(i1, i2);
```

Can be written like:

```
Comparator<Integer> c = Integer::compare;
```

Method References

```
Arrays.sort(rosterAsArray,
    (Person a, Person b) -> {
        return a.getBirthday()
               .compareTo(b.getBirthday());
    }
);
```

However, this method to compare the birth dates of two Person instances already exists as Person.compareByAge. You can invoke this method instead in the body of the lambda expression:

```
Arrays.sort(rosterAsArray,
        (a, b) -> Person.compareByAge(a, b));
```

Because this lambda expression invokes an existing method, you can use a method reference instead of a lambda expression:

```
Arrays.sort(rosterAsArray, Person::compareByAge);
```

```
public class Person {

    public enum Sex {
        MALE, FEMALE
    }

    String name;
    Date birthday;
    Sex gender;
    String emailAddress;

    public static int compareByAge
    (Person a, Person b) {
        return
        a.birthday
         .compareTo(b.birthday);
    }
}
```

Method References

```
Arrays.sort(rosterAsArray, Person::compareByAge);
```

The method reference `Person::compareByAge` is semantically the same as the lambda expression `(a, b) -> Person.compareByAge(a, b)`.

Each has the following characteristics:
Its formal parameter list is copied from `Comparator<Person>.compare`, which is `(Person, Person)`.
Its body calls the method `Person.compareByAge`.

There are four kinds of method references:

Kind	Example
Reference to a static method	`ContainingClass::staticMethodName`
Reference to an instance method of a particular object	`ContainingObject::instanceMethodName`
Reference to an instance method of an arbitrary object of particular type	`ContainingType::methodName`
Reference to a constructor	`ClassName::new`

Reference to an Instance Method of an Arbitrary Object of a Particular Type

```
String[] stringArray = { "Barbara", "James", "Mary", "John",
           "Patricia", "Robert", "Michael", "Linda" };
Arrays.sort(stringArray, String::compareToIgnoreCase);
```

The equivalent lambda expression for the method reference `String::compareToIgnoreCase` would have the formal parameter list `(String a, String b)`, where `a` and `b` are arbitrary names used to better describe this example.

The method reference would invoke the method `a.compareToIgnoreCase(b)`.

Reference to a Constructor

```
public static <T, SOURCE extends Collection<T>, DEST extends Collection<T>>
    DEST transferElements(SOURCE sourceCollection,
                          Supplier<DEST> collectionFactory) {
        DEST result = collectionFactory.get();
        for (T t : sourceCollection) result.add(t);
        return result;
}
```

The functional interface `Supplier` contains one method `get` that takes no arguments and returns an object. Consequently, you can invoke the method `transferElements` with a lambda expression as follows:

```
Set<Person> rosterSetLambda =
     transferElements(roster, () -> { return new HashSet<>(); });
```

You can use a constructor reference in place of the lambda expression as follows:

```
Set<Person> rosterSet = transferElements(roster, HashSet::new);
```

The Java compiler infers that you want to create a HashSet collection that contains elements of type Person. Alternatively, you can specify this as follows:

```
Set<Person> rosterSet = transferElements(roster, HashSet<Person>::new);
```

Method References Examples

Examples:

FuncInterfaceTutor

FuncInterfaceTask

Data Streams

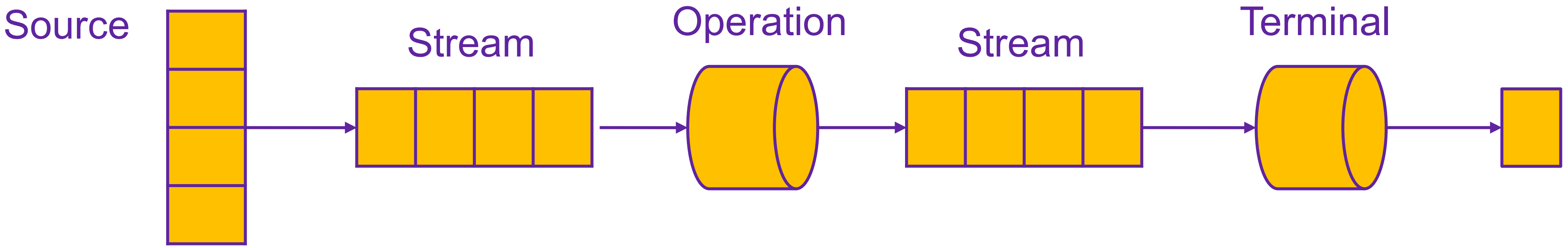
What is a Stream?

Technical answer: a typed interface

```
public interface Stream<T> extends BaseStream<T, Stream<T>> {
   // ...
}
```

Why are streams so *efficient*?

- They may work in parallel to leverage the computing power of multicore CPUs;
- They can be pipelined to avoid unnecessary intermediary computations



Why can’t a Collection be a Stream?

- The key is the difference between eager and lazy operations. Most operations in the Stream are lazy.

What is a Stream?

- An object on which one can define *operations*
- An object that does not hold any data
- An object that should not change the data it processes
- An object able to process data in « one pass »
- An object optimized from the algorithm point of view, and able to process data in parallel

How to Create a Stream?

- Using static method Stream.of():

```
Stream.of(1,2,3);
```

- From array

```
String[] arr = {"one", "two", ”three" };
stream = Stream.of(arr);
```

- From collection

```
List<Person> persons;
Stream<Person> stream = persons.stream();
```

- Using generate()

```
Stream<String> stream =
  Stream.generate(() -> "test").limit(10);
```

Map/Filter/Reduce

Map / Filter / Reduce

Let’s take a list of Person:

```
List<Person> list = new ArrayList<>() ;
```

Suppose we want to compute the « average of the age of people older than 20 »

Let’s first convert it into stream…

```
list.stream()
```

Map/Filter/Reduce

List<Person> persons;
persons.stream()

stream of persons

Person

```
map( (Person p) -> p.getAge() )
```

24 18 34 44 52

```
filter( age -> age>20 )
```

24 34 44 52

```
average()
```

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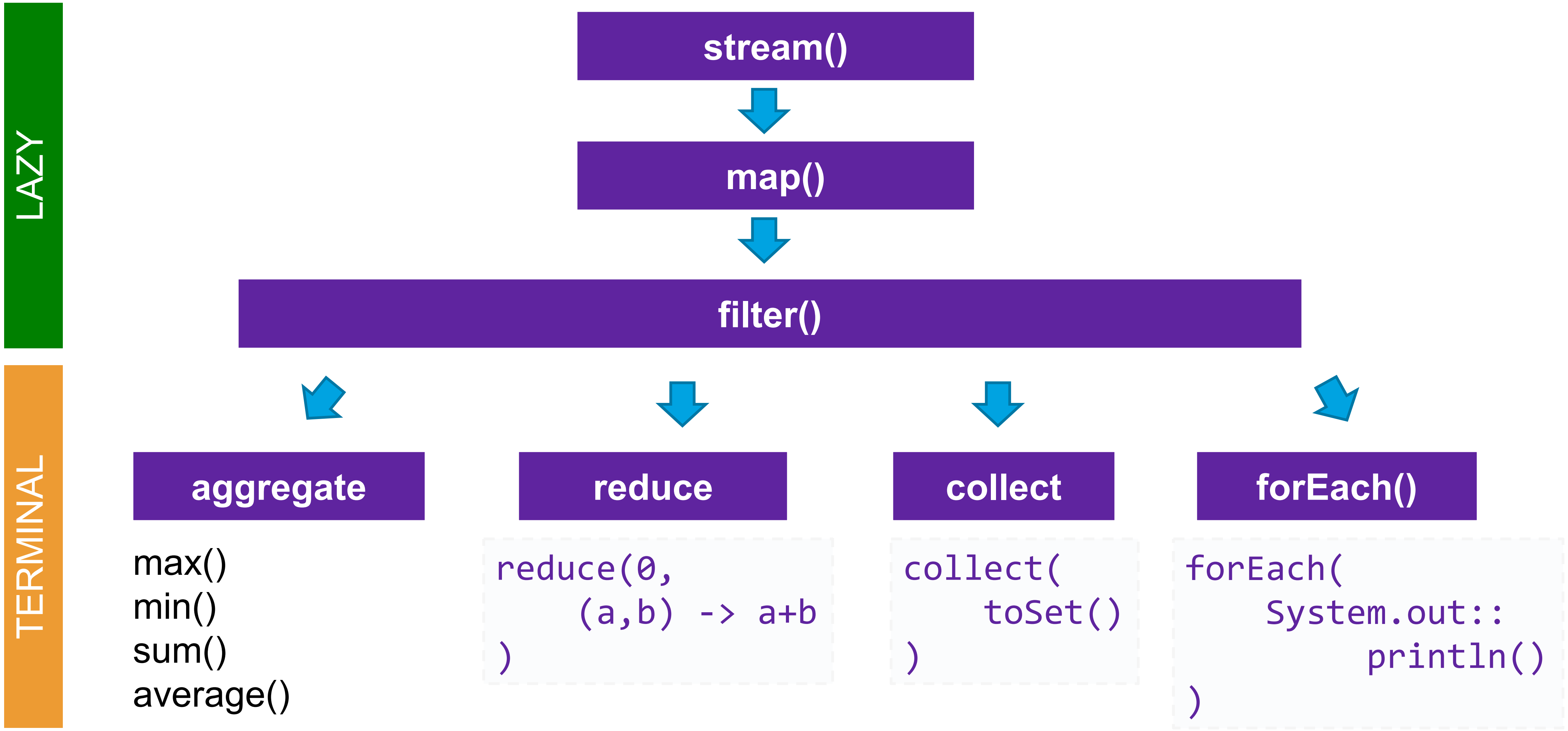
Lazy and Terminal Operations



Aggregation functions

Available aggregations:

- max(), min(), count()

Boolean reductions

- allMatch(), noneMatch(), anyMatch()

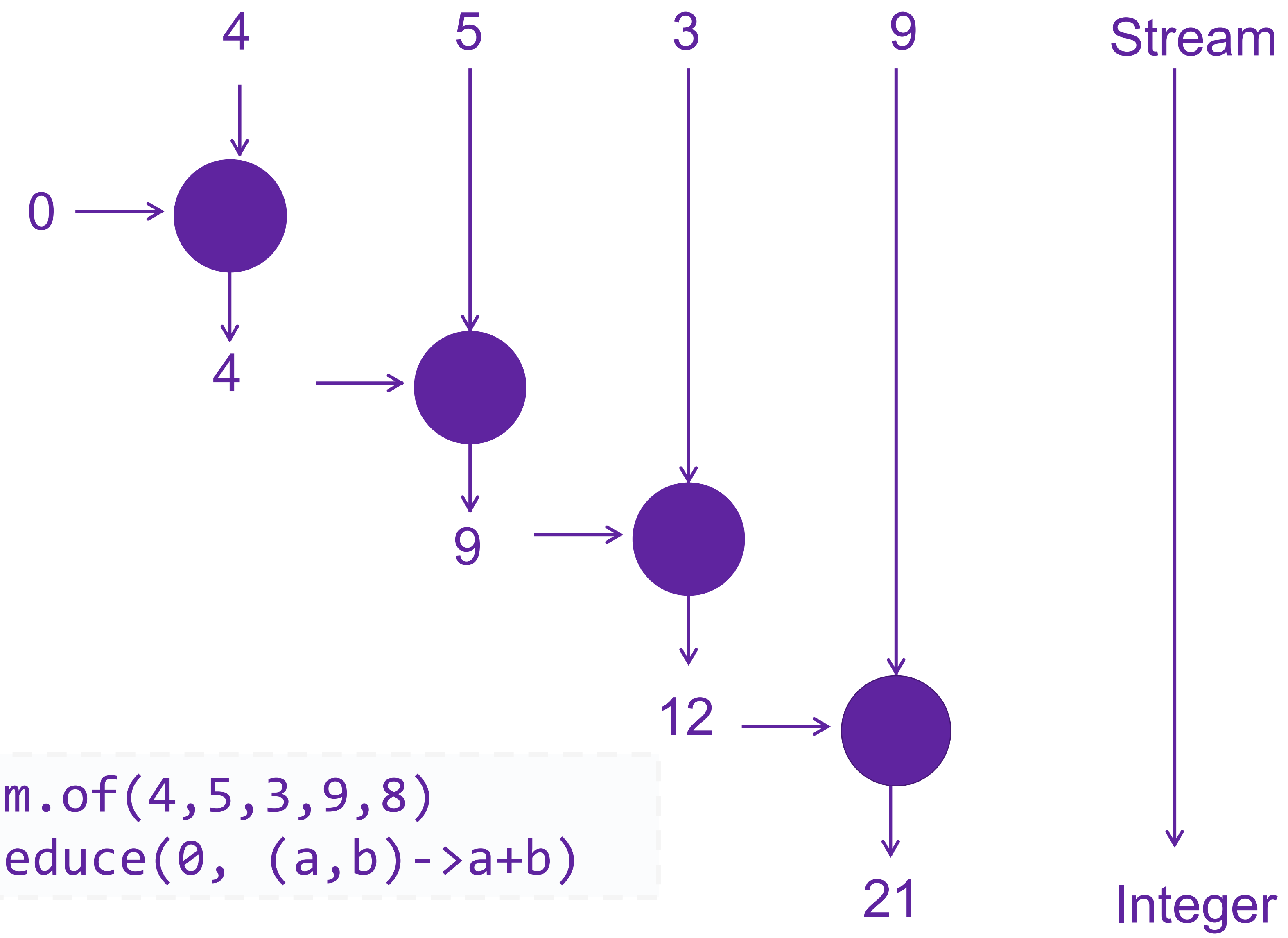
Reductions that return an optional

- findFirst(), findAny()

Reductions are *terminal* operations that trigger the processing of data:

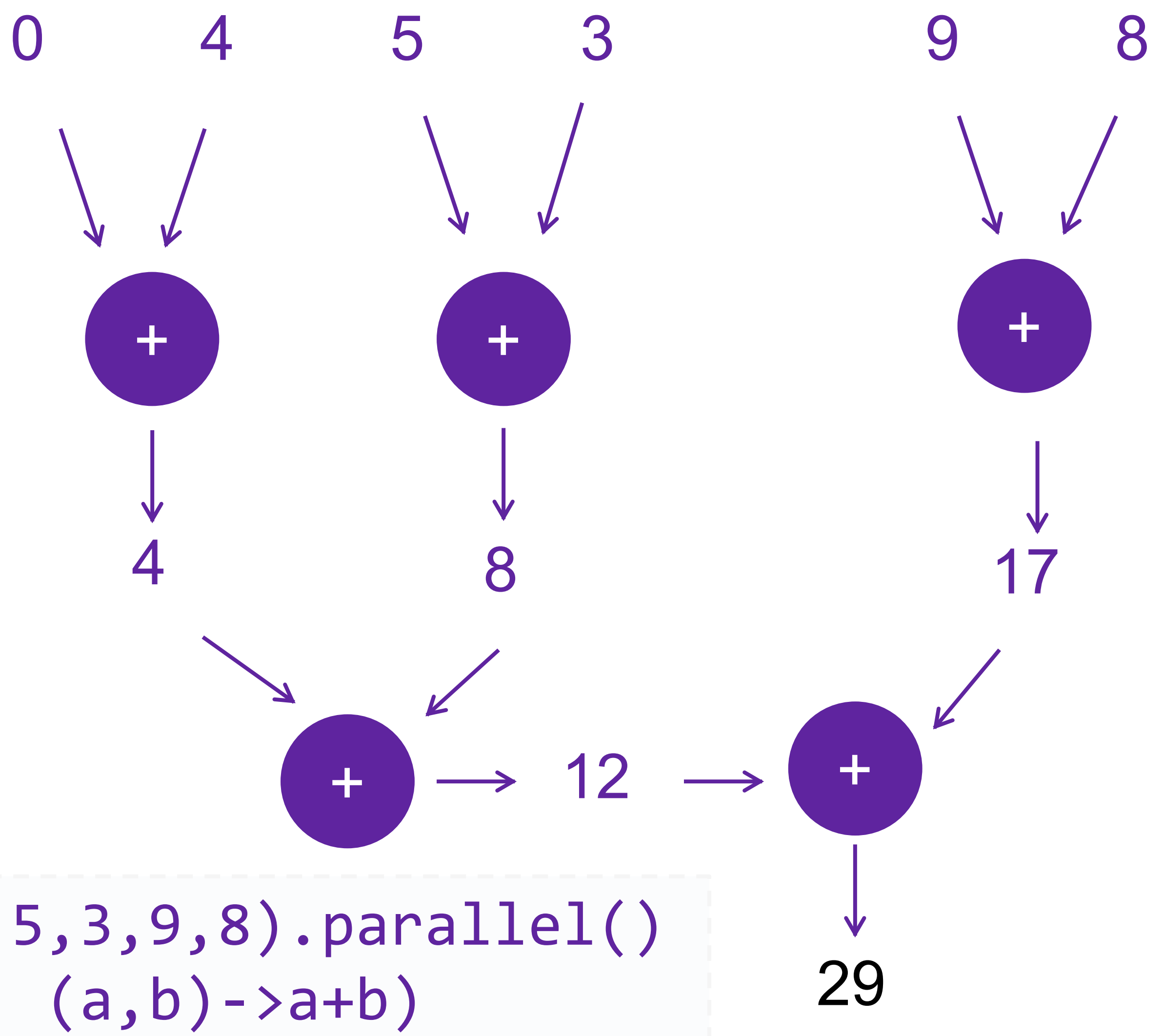
```
persons.map(person -> person.getAge())
    .allMatch(age -> age > 20); // terminal operation
```

Reduce




```
Stream.of(4,5,3,9,8)
    .reduce(0, (a,b)->a+b)
```

Reduce in Parallel Processing




```
Stream.of(4,5,3,9,8).parallel()
  .reduce(0, (a,b)->a+b)
```

Example::
ReduceTutor

forEach(Consumer)

forEach(Consumer consumer) iterates over all stream elements and applies the consumer

```
@FunctionalInterface
public interface Consumer<T> {
    void accept(T t);
}
```

Consumer<T> is a *functional interface*

It can be implemented by a lambda expression

```
Consumer<T> c = p -> System.out.println(p);
Consumer<T> c = System.out::println;
Stream.of(1,2,3).forEach(c);
```

Operations on Streams

However, Consumer<T> is a bit more complex:

```
@FunctionalInterface
public interface Consumer<T> {
    void accept(T t);

    default Consumer<T> andThen(Consumer<? super T> after) {
            Objects.requireNonNull(after);
            return (T t) -> { accept(t); after.accept(t); };
    }
}
```

Consumers may be chained!

Consumer Chaining

```
List<String> list = new ArrayList<>();
Consumer<String> c1 = s -> list.add(s);
Consumer<String> c2 = s -> System.out.println(s);


List<String> list = new ArrayList<>();
Consumer<String> c1 = list::add;
Consumer<String> c2 = System.out::println;
Consumer<String> c3 = c1.andThen(c2);
Stream.of(1,2,3).forEach(c3);
```

Example:
ChainConsumers

Chaining consumers is the only way to have several consumers on a single stream - forEach() does not return anything.

Predicates Combination

Predicates

```
Predicate<String> p1 = s -> s.length() < 20;
Predicate<String> p2 = s -> s.length() > 10;

Predicate<String> p3 = p1.and(p2);


@FunctionalInterface
public interface Predicate<T> {
    boolean test(T t);

    default Predicate<T> and(Predicate<? super T> other) {
            Objects.requireNonNull(other);
        return (t) -> test(t) && other.test(t);
    }

}
```

Predicate.isEqual()

Predicates

```
Predicate<String> id = Predicate.isEqual(target);


@FunctionalInterface
public interface Predicate<T> {
    boolean test(T t);

    static <T> Predicate<T> isEqual(Object targetRef) {
       return (null == targetRef)
               ? Objects::isNull
               : object -> targetRef.equals(object);
         }
}
```

Predicates

```
List<String> list = new ArrayList<>();
Stream<Person> stream = list.stream();
Stream<Person> filtered =
     stream.filter(person -> person.getAge() > 20);
```

A predicate is taken as a parameter:

```
Predicate<Person> p = person -> person.getAge() > 20;
```

Predicates

The Predicate interface:

```
@FunctionalInterface
public interface Predicate<T> {
    boolean test(T t);
    default Predicate<T> and(Predicate<? super T> other) { ... }
    default Predicate<T> or(Predicate<? super T> other) { ... }
    default Predicate<T> negate() { ... }
}
Predicate<Integer> p1 = i -> i > 20;
Predicate<Integer> p2 = i -> i < 30;
Predicate<Integer> p3 = i -> i == 0;

Predicate<Integer> p = p1.and(p2).or(p3); // (p1 && p2) || p3
Predicate<Integer> p = p3.or(p1).and(p2); // p3 || (p1 && p2) => (p3 OR p1) && p2
```

Warning: method calls do not handle priorities

Predicates

Predicate interface, with static method:

Example:
PredicateTutor

```
@FunctionalInterface
public interface Predicate<T> {
    boolean test(T t);
    // default methods
    static <T> Predicate<T> isEqual(Object o) { ... }
}

Predicate<String> p = Predicate.isEqual("two") ;
Stream<String> stream1 = Stream.of("one", "two", "three");
Stream<String> stream2 = stream1.filter(p.negate()) ;
```

The filter method returns a Stream, which is the new instance.

peek(Consumer)

`Stream peek(Consumer)`

returns a stream consisting of the elements of this stream, additionally performing the provided action on each element, as they are consumed from the resulting stream.

```
// What does this code do?
List<String> result = new ArrayList<>();
List<Person> persons = ... ;
persons.stream()
       .peek(System.out::println)
       .filter(person -> person.getAge() > 20)
       .peek(result::add);
```

Hint: the peek() method returns a Stream

Summary

- The Stream API defines *intermediary operations*

We've seen 3 operations:

- forEach(Consumer) (not lazy)
- peek(Consumer) (lazy)
- filter(Predicate) (lazy)

Stream Mapping

Mapping Operation

A mapper is modeled by the Function interface with default methods to chain and compose mappings:

```
@FunctionalInterface
public interface Function<T, R> {

   R apply(T t);
   default <V> Function<V, R> compose(Function<V, T> before);
   default <V> Function<T, V> andThen(Function<R, V> after);

   static <T> Function<T, T> identity() {
       return t -> t;
   }

}
```

Example

```
UnaryOperator<Integer> f1 = a->a+1;
 UnaryOperator<Integer> f2 = a->a*2;
 int x = 1;
 System.out.println(f1.andThen(f2).apply(x));  // f2(f1(x)) =4
 System.out.println(f1.compose(f2).apply(x));  // f1(f2(x)) =3
 UnaryOperator<Integer> f3 = UnaryOperator.identity();
 print(10, f1);
 print(10, UnaryOperator.identity());
 print(10, z->z);
```

Flat Mapping Operation

Method flatMap()

```
<R> Stream<R> flatMap(Function<T, Stream<R>> flatMapper);
<R> Stream<R> map(Function<T, R> mapper);
```

- The flatMapper takes an element of type T, and returns an element of type Stream<R>
- If the flatMap was a regular map, it would return a Stream<Stream<R>>
- Thus a « stream of streams »

- But it is a flatMap!
- Thus the « stream of streams » is flattened, and becomes a stream

Flat Mapping Operation

Lets calculate the average age of parents

FlatMapExample

Person Person Person Person

```
map( (Person p) ->
    Stream.of(p.getFather().getAge(),
                    p.getMother().getAge() )
```

{48,52} {70,64} {44,44} {52,54}

```
flatMap( l->l.stream() )
```

48 52 70 64 44 44 52 54

```
average()
```

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Aggregation and Reduction

Reduction Step

How does it work?

```
List<Integer> ages = ... ;
Stream<Integer> stream = ages.stream();
Integer sum = stream.reduce(0,
       (age1, age2) -> age1 + age2);
```

- 1st argument: identity element of the reduction operation
- 2nd argument: reduction operation of the type BinaryOperator<T>

BinaryOperator

A BinaryOperator is a special case of BiFunction

```
@FunctionalInterface
public interface BiFunction<T, U, R> {
    R apply(T t, U u);
    //plus default methods
}


@FunctionalInterface
public interface BinaryOperator<T> extends BiFunction<T, T, T> {
    // T apply(T t1, T t2);
    // plus static methods
}
```

Identity Element

The bi-function takes two arguments, so…

- What happens if the Stream is empty?
- What happens if the Stream has only one element?

- The reduction of an empty Stream is the identity element;
- If the Stream has only one element, then the reduction is that element.

Aggregation

```java
Stream<Integer> stream = ...;
BinaryOperation<Integer> sum = (i1, i2) -> i1 + i2;
Integer id = 0; // identity element for the sum

Stream<Integer> stream = Stream.empty();
int red = stream.reduce(id, sum);

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

Will print:

> 0

Aggregation

```java
Stream<Integer> stream = ...;
BinaryOperation<Integer> sum = (i1, i2) -> i1 + i2;
Integer id = 0; // identity element for the sum

Stream<Integer> stream = Stream.of(1);
int red = stream.reduce(id, sum);

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

Will print:

> 1

Aggregation

```
Stream<Integer> stream = ...;
BinaryOperation<Integer> sum = (i1, i2) -> i1 + i2;
Integer id = 0; // identity element for the sum

Stream<Integer> stream = Stream.of(1, 2, 3, 4);
int red = stream.reduce(id, sum);

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

Will print:

> 10

Aggregation: Corner Case

Suppose the reduction is the max:

```
BinaryOperation<Integer> max =
   (i1, i2) -> i1 > i2 ? i1 : i2;
```

- The problem is there’s no identity element for that max reduction;
- So, the max of this empty Stream is undefined.

Aggregation: Corner Case

Then what is the return type of this call?

```
List<Integer> ages = ... ;
Stream<Integer> stream = ages.stream();
...
max = stream.max();
```

- If it is an int, then the default value is 0…
- And if an Integer, the default value is null.

Optionals

```
List<Integer> ages = ... ;
Stream<Integer> stream = ages.stream();
...
Optional<Integer> max = stream.max();
```

Optional means « there might not be any result »

Optional

value

Optionals

How to use an Optional?

Example:
OptionalTutor

```
Optional<String> opt = ... ;
if (opt.isPresent()) {
   String s = opt.get() ;
} else {

}
```

- The method isPresent() returns true if there is something in the optional
- The method get() returns the value held by this optional
- The method orElse() encapsulates both calls

```
String s = opt.orElse("") ; // defines a default value
```

- The method orElseThrow() defines a thrown exception

```
String s = opt.orElseThrow(()->new MyException("nothing inside"));
```

Collectors

Collectors

- There is another type of reduction
- It is called « mutable » reduction
- Instead of aggregating elements, this reduction puts them in a « container »

Collecting in a List

```
List<Person> persons = ... ;

List<String> result =
       persons.stream()
        .filter(person -> person.getAge() > 20)
        .map(Person::getLastName)
        .collect(Collectors.toList());
```

The result is a List of Strings with all the names of people in persons older than 20.

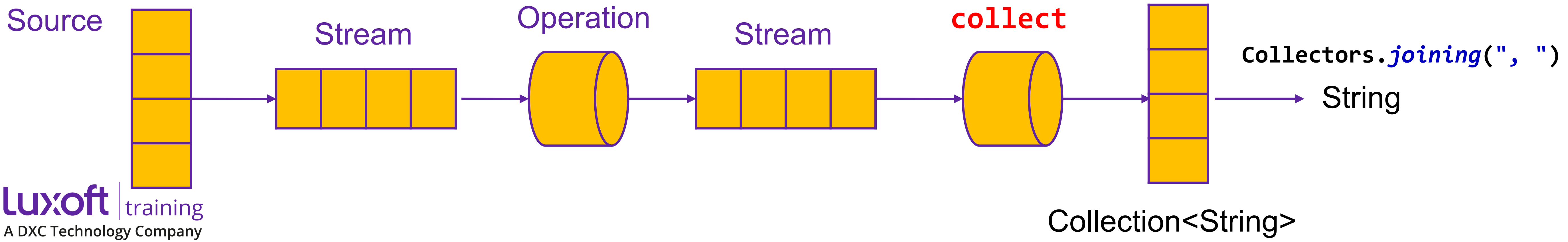
```
Collectors.toList()
Collectors.toSet()
Map<Integer, String> Collectors.toMap(Person::getAge, Person::getLastName) // NOT OK
Map<Integer, String> Collectors.toMap(Person::getId, Person::getLastName) // OK
```

Collecting in a String

```
List<Person> persons = ... ;

String result = persons.stream()
        .filter(person -> person.getAge() > 20)
                .map(Person::getLastName)
        .collect(Collectors.joining(", "));
```

The result is a String with all the names of people in persons older than 20, separated by a comma.



Collecting in a Map

```
List<Person> persons = ... ;

Map<Integer, List<Person>> result =
persons.stream()
    .filter(person -> person.getAge() > 20)
    .collect(Collectors.groupingBy(Person::getAge));
```

```
Map<Integer, List<Person>>
```

25 -> [Mary, John]

30 -> [Joseph]

35 -> [Jane, David]

The result is a Map containing the people of persons older than 20:

- The keys are the ages of the people
- The values are the lists of the people of that age

It is possible to « post-process » the values, with a *downstream collector*

Collecting in a Map

```
List<Person> persons = ... ;

Map<Integer, Long> result =
persons.stream()
       .filter(person -> person.getAge() > 20)
       .collect(Collectors.groupingBy(Person::getAge,
                                 Collectors.counting()));
```

Example:
GroupByTutor
CollectorsTutor

Collectors.counting() just counts the number of people of each age.

`Map<Integer, List<Person>>`		`Map<Integer, Long>`
25 -> [Mary, John]	`Collectors.counting()` →	**25 -> 2**
30 -> [Joseph]		**30 -> 1**
35 -> [Jane, David]		**35 -> 2**

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Collecting in a Map

```
List<Person> persons = ... ;

Map<Integer, Long> result =
persons.stream()
        .filter(person -> person.getAge() > 20)
        .collect(Collectors.groupingBy(Person::getAge,
                                     Collectors.joining(", ")));
```

Example:
GroupByTutor
CollectorsTutor

Collectors.counting() just counts the number of people of each age.

`Map<Integer, List<Person>>`

25 -> [Mary, John]

30 -> [Joseph]

35 -> [Jane, David]

`Collectors.joining(",")`

`Collectors.reducing("", (a,b)->a+","+b)`

`Map<Integer, String>`

25 -> Mary, John

30 -> Joseph

35 -> Jane, David

Special Stream Types

IntStream

IntStream - a sequence of primitive int-valued elements supporting sequential and parallel aggregate operations. This is the int primitive specialization of Stream.

```
IntStream.of(2,3,3,4).max();


List<Integer> numbers = IntStream.range(1, 3)
        .boxed()
        .collect(Collectors.toList());
```

- Other primitive value streams are:
    - **DoubleStream**
    - **LongStream**

IntStream Usage Examples

IntStreamTutor

```
List<String> ls = Arrays.asList(new String[] {"1","2","3"});
OptionalInt ints = ls.stream().mapToInt(Integer::parseInt).max();
int optInt = ls.stream().mapToInt(Integer::parseInt).max().orElse(5);
```

```
// get list of 1 and 2 Integers (to get 1,2,3 use rangeClosed())
List<Integer> numbers = IntStream.range(1, 3).boxed()
        .collect(Collectors.toList());
```

```
OptionalInt max = IntStream.of(5, 10).max(); // 10
```

```
OptionalInt one = IntStream.generate(() -> 1)
        .limit(10).distinct().findFirst(); // 1
```

```
// same as generate, but with a seed -
// will iterate from 0 and for every element will add 3,
// so 0 + 3, 3 + 3 and so on
List<Integer> numbers = IntStream.iterate(0, n -> n + 3).limit(3)
        .boxed().collect(Collectors.toList());
```

```
IntStream first = IntStream.builder().add(10).add(20).build();
IntStream second = IntStream.builder().add(10).build();
IntStream third = IntStream.concat(first, second); // 10,20,10
```

Random

Random is used to generate a stream of pseudorandom numbers.

Example:
RandomTutor

- If two instances of Random are created with the same seed, and the same sequence of method calls is made for each, they will generate and return identical sequences of numbers.
- Instances of Random are **threadsafe**. However, the concurrent use of the same Random instance across threads may encounter **poor performance**. Instead, consider using **ThreadLocalRandom** in multithreaded designs.
- Instances of Random are **not cryptographically secure**. Instead, consider using **SecureRandom** to get a cryptographically secure pseudo-random number generator

Parallel Streams

Example:
ParallelTest
ForkJoinSum
ForkJoinFreq

`Stream parallel()`

returns an equivalent stream that is parallel.

`Stream unordered()`

returns an equivalent stream that is unordered. May return itself, either because the stream was already unordered, or the underlying stream state was modified to be unordered.

Thank you!

Please share your feedback.
Your opinion is important to us!

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