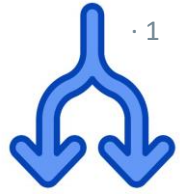


# Practical Concurrent and Parallel Programming X

## Streams, Parallel Streams and RxJava

Jørgen Staunstrup

# Agenda



- **Java Streams**

- RxJava

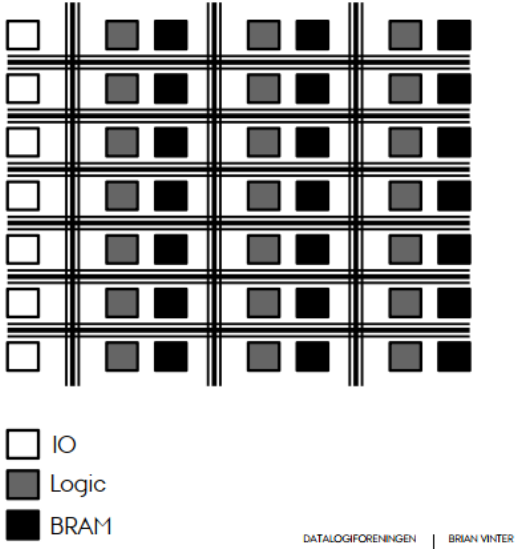

Previously on PCPP:
**Distribution** (similar tasks to many threads)


Streams:
**Pipeline** (different tasks to each thread F, G, H, …)

# Motivation



Supercomputer

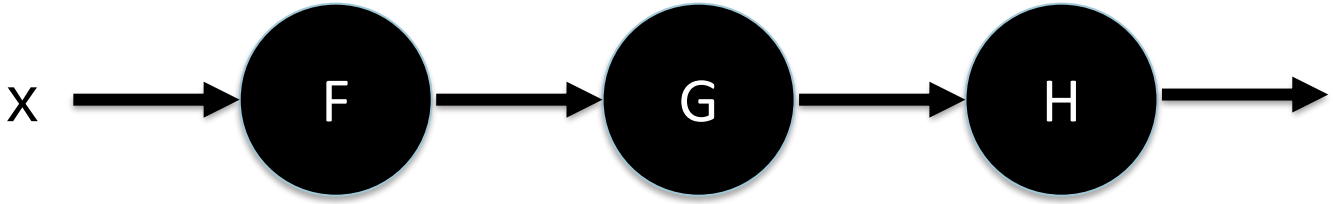



...

- Data is often communicated as a stream
- from a file,
- from the internet
- from the user interface
- …

# Java Stream





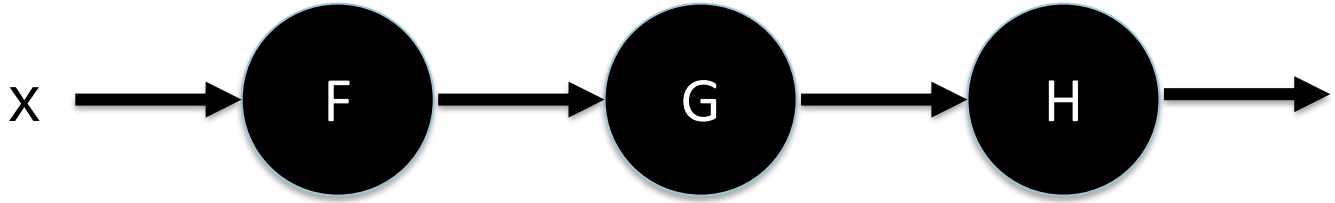

Java Stream

```
x().F().G().H()
```

Closely related to: H(G(F(x))) functional programming

# Stream example






X is a stream of words: ….. ablaut able ableeze … zyme

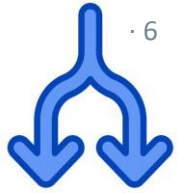
F discards all words with 1 character

G discards all words that are capitalized

H counts number of words

# Java (imperative)





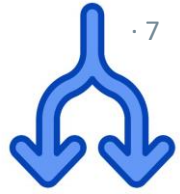
```
public static String F(String s) {
  return s.length() > 1 ? s : null;
}

public static String G(String s) {
  if (s==null) return null;
  return Character.isLowerCase(s.charAt(0)) ? s : null;
}

public static int H(String s) {
  return s==null ? 0 : 1;
}
...
while ((line= reader.readLine()) != null) {
  word= F(line);
  smallLetters= G(word);
  count+= H(smallLetters);
}
```

# Java stream





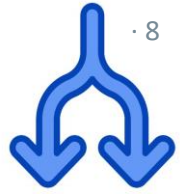
```
x().F().G().H()
```

```
count= readWords(filename)  // makes a stream of words
   .filter( w -> w.length()>1 ) // F
   .filter( w -> Character.isLowerCase(w.charAt(0)) ) // G
   .count(); // H
```

```
count= readWords(filename)
   .parallel()
   .filter( w -> w.length()>1 )
   .filter( w -> Character.isLowerCase(w.charAt(0)) )
   .count();
```

# Java stream



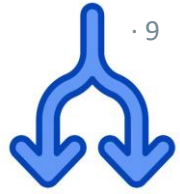


```
x().F().G().H()
```

```
count= readWords(filename)  // makes a stream of words
   .filter( w -> w.length()>1 ) // F
   .filter( w -> Character.isLowerCase(w.charAt(0)) ) // G
   .count(); // H
```

A sequence of stream method calls is commonly known as *stream pipeline*

Lambda expressions



## The streams are lazy (driven by the terminal operation)

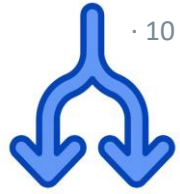
```
count= readWords(filename)  // source
   .filter( w -> w.length()>1 ) // intermediate
   .filter( w -> Character.isLowerCase(w.charAt(0)) )
   .count(); // terminal
```

There are three different types of stream elements:

- *sources* (arrays, collections, IO, generators)
- *intermediate operations* (transforming one stream into another (e.g. filter)
- *terminal operations* ( count, sum, forEach, ...)

# Stream sources





## Provides the data for the stream

Examples of stream sources are:

- Input (files or network)
- The Arrays class has a number of utilities, for example:
  `Arrays.stream(arr)`

Other examples of collections?

https://howtodoinjava.com/java/stream/java-streams-by-examples/

# Intermediate operators



## A computation/transformation on *each* element of the string

See Sestoft's Java precisely and the java documentation for a complete list

Examples of intermediate operations are:

- filter – takes a lambda expression lambda returning a boolean, if the boolean is true the element is included in the output stream
- map – transforms each element
- limit(*n*) – returns a stream of the first *n* elements
- skip(*n*) – returns a stream without the first *n* elements
- distinct – returns a stream without duplicated elements
- sorted - returns a stream with the elements sorted

# Intermediate operations



```
count= readWords(filename)  // makes a stream of words
   .filter( w -> w.length()>1 ) // F
   .filter( w -> Character.isLowerCase(w.charAt(0)) ) // G
   .count(); // H
```

Which operation(s) is/are intermediate?

# BufferedReader (file)



Exercise: 10.2

```
public static void main(String[] args) {
    String filename = "src/main/resources/english-words.txt";
    System.out.println( readWords(filename).count());
}

public static Stream<String> readWords(String filename) {
  try {
    BufferedReader reader= new BufferedReader(new FileReader(filename));
      return ... // TO DO: Implement properly
} catch (IOException exn) { return Stream.<String>empty();  }
}
```

https://docs.oracle.com/javase/7/docs/api/java/io/BufferedReader.html

| | |
|---|---|
| `Stream<String>` | `lines()`<br>Returns a `Stream`, the elements of which are lines read from this `BufferedReader` |

# BufferedReader (URL)



Exercise: 10.2

```
String filename = "https://staunstrups.dk/jst/english-words.txt";
System.out.println(readWordsFromURL(urlname).count());


public static Stream<String> readWordsFromURL(String urlname) {
  try {
    HttpURLConnection connection=
              (HttpURLConnection) new URL(urlname).openConnection();
    BufferedReader reader=
              new BufferedReader(new InputStreamReader(connection.getInputStream()));
    return reader.lines();
 } catch (IOException  exn) { return Stream.<String>empty(); }
}
```

https://docs.oracle.com/javase/7/docs/api/java/io/BufferedReader.html

# Defining a Java stream



- Using the Arrays class
  - `Arrrays.stream(array)`
- Most Java collections have a method `stream()` that turns the collection into a stream
- `Stream.of(1,2,3,4)` creates a stream with those elements
- Functional iterators for infinite streams
  - `IntStream nats = IntStream.iterate(0, x->x+1)`
- `BufferedReader` (important for exercises)

| | |
|---|---|
| `Stream<String>` | `lines()`<br>Returns a `Stream`, the elements of which are lines read from this `BufferedReader` |

# Terminal operations



## Provides the *result* of the stream computation

Examples of terminal operations are:

- min, max, sum, average, count (number streams)
- forEach e.g., forEach(System.out::println)
- reduce / collect (introduced shortly)

https://howtodoinjava.com/java/stream/java-streams-by-examples/

# Terminal operations

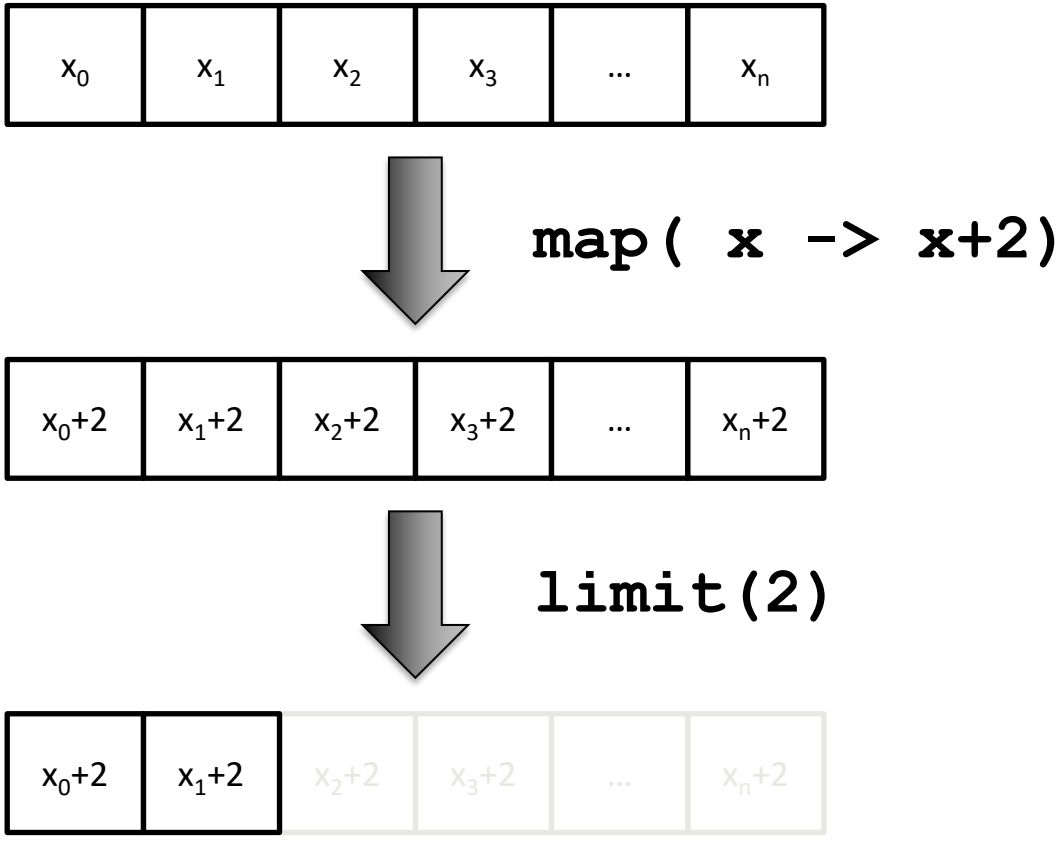


```
count= readWords(filename)  // makes a stream of words
   .filter( w -> w.length()>1 ) // F
   .filter( w -> Character.isLowerCase(w.charAt(0)) ) // G
   .count(); // H
```

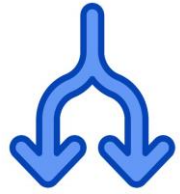
Which operation(s) is/are terminal?

# Intermediate operations





# Terminal operation reduce



- Reduce all elements of the stream to a single value by applying a function
- **`reduce(identity, accumulator)`**
  - **`identity`**: The identity element is both the initial value of the reduction and the default result if there are no elements in the stream.
  - **`accumulator`**: The accumulator function takes two parameters: a partial result of the reduction and the next element of the stream.
- Example
  - Sum of squares of first 100 natural numbers
    - **`IntStream.range(0,100).reduce(0, (a,b) -> a+b*b))`**

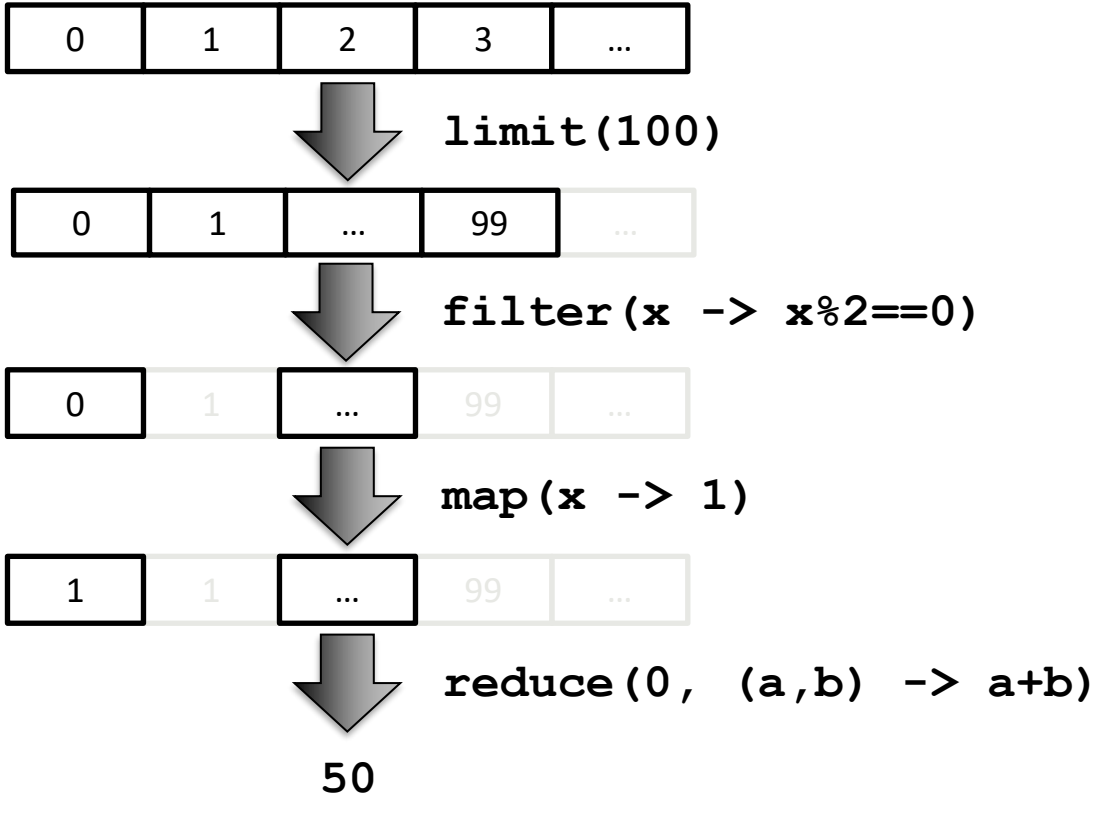
# Reduce without identity



- Reduce can also be called without identity parameter
- Then it returns an `Optional` value
  - A container object which may or may not contain a non-null value.
  - Needed in case the reduction is performed on an empty stream.
- Example
  - Sum of squares of first 100 natural numbers
    - `IntStream.range(0,100).reduce((a,b) -> a+b*b).orElse(0))`
- There are other built-in reductions: sum, max, min, average, etc…

# Example with everything so far





# Example with everything so far



- Here is an example with everything we have seen so far
  - Amount of even numbers in the range 0 to 99

```
IntStream.iterate(0,x->x+1)
         .limit(100)
         .filter(x -> x%2==0)
         .map(x -> 1)
         .reduce(0, (a,b) -> a+b);
```

# Ordering



Streams may or may not have a defined *encounter order*

- **`List`** and **`Arrays`** are intrinsically ordered
- **`HashSet`** is not ordered

An intermediate operation e.g., **`sorted`** transforms an unordered **`Stream`** into an ordered **`Stream`**

https://docs.oracle.com/javase/8/docs/api/java/util/stream/package-summary.html#Ordering

# Parallel (intermediate)



```
IntStream.range(0, range)
.parallel()
.filter(i -> isPrime(i))
.count()
```

← ordered

← ?

`IntStream.range` produces an *ordered* stream

`parallel` is an operation in `BaseStream`

OVERVIEW PACKAGE CLASS USE TREE DEPRECATED INDEX HELP

PREV CLASS **NEXT CLASS** FRAMES NO FRAMES ALL CLASSES

SUMMARY: NESTED | FIELD | CONSTR | METHOD DETAIL: FIELD | CONSTR | METHOD

compact1, compact2, compact3
java.util.stream

**Interface BaseStream<T,S extends BaseStream<T,S>>**

`parallel()`

Returns an equivalent stream that is parallel.

https://docs.oracle.com/javase/8/docs/api/java/util/stream/BaseStream.html

# Interfering streams



- If you try to modify a stream you are operating you will get a `ConcurrentModificationException` at runtime
  - So don't do it ☺
- Cannot be detected at compile time. It depends on the programmer.
- From the Java documentation
  - ***Streams enable you to execute possibly-parallel aggregate operations*** *over a variety of data sources, including even non-thread-safe collections such as ArrayList.* ***This is possible only if we can prevent interference with the data source during the execution of a stream pipeline****. […] For most data sources, preventing interference means ensuring that the data source is not modified at all during the execution of the stream pipeline.*

# Example: stream of objects



```
class Employee {
  int id;
  String dept;
  int salary;

  public Employee(int id, String dept, int salary) {
    this.id     = id;
    this.dept   = dept;
    this.salary = salary;
  }
  public int getId() { return this.id; }
  public String getDept() { return this.dept; }
  public int getSalary() { return this.salary; }
}

static private Stream<Employee> randomEmployees() {
...
}
```

# Terminal operation collect



- It is a reduction operation that allows to collect the results of a stream into a Java collection or summarize them using complex criteria

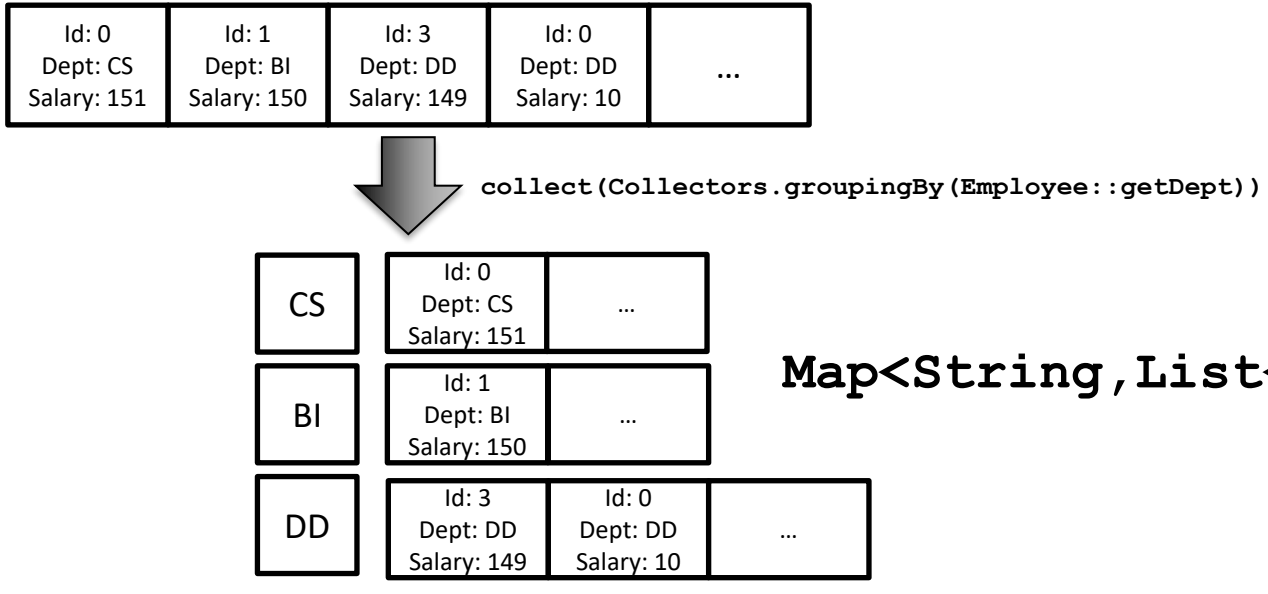
- For instance, converting a stream into a list

```
List<Integer> l = randomEmployees()
        .limit(50)
        .map(Employee::getId)
        .collect(Collectors.toList());
```

# Terminal operation: collect + groupingBy

- Group employees by department

```
Map<String,List<Employee>> m = randomEmployees()
        .limit(50)
        .collect(Collectors.groupingBy(Employee::getDept));
```



# Printing the result



```
randomEmployees()
   .limit(50)
   .collect(Collectors.groupingByConcurrent(Employee::getDept))
    .forEach((k,v) ->
     System.out.println(k+":     "+v
        .stream()
       .map(Employee::getId)
       .collect(Collectors.toList())
     ));
```

# Java Parallel Streams



- You can create a parallel stream by calling
  - **`parallelStream()`** on, e.g., a collection, or
  - **`parallel()`** on a stream

# Java Parallel Streams

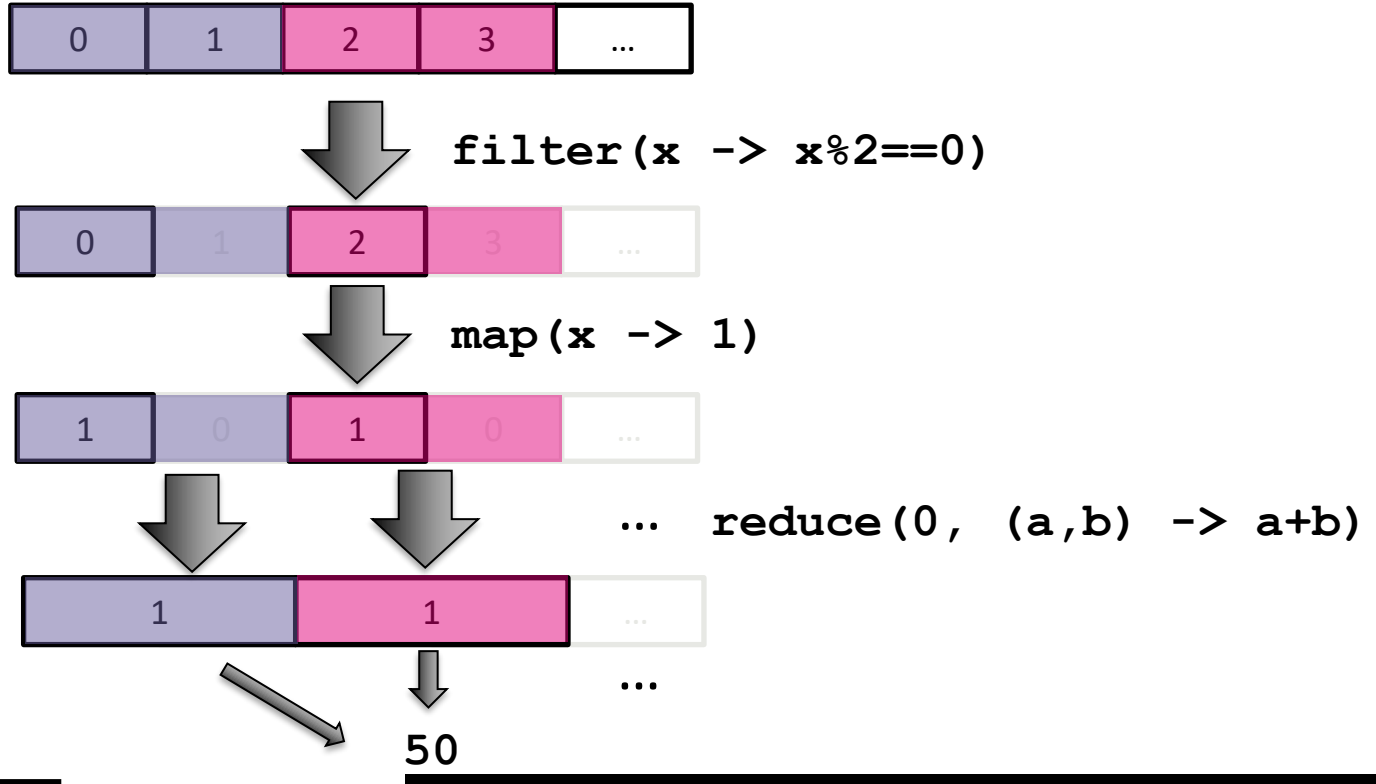


- Parallelization of streams is very easy (remember the beginning of the lecture). Disjoint streams (from the original stream) are assigned to distinct threads from a thread pool

Thread 1

Thread 2

⋮



# Java Parallel Streams | Processing order



- Since execution is parallel the processing of the stream is not guaranteed to in order
- For instance, run this program
  - `IntStream.range(0,10).parallel().forEach(System.out::println);`
- In this case, it may be mitigated with **`forEachOrdered`**
  - `IntStream.range(0,10).parallel().forEachOrdered(System.out::println);`

# Java Parallel Streams | Grouping

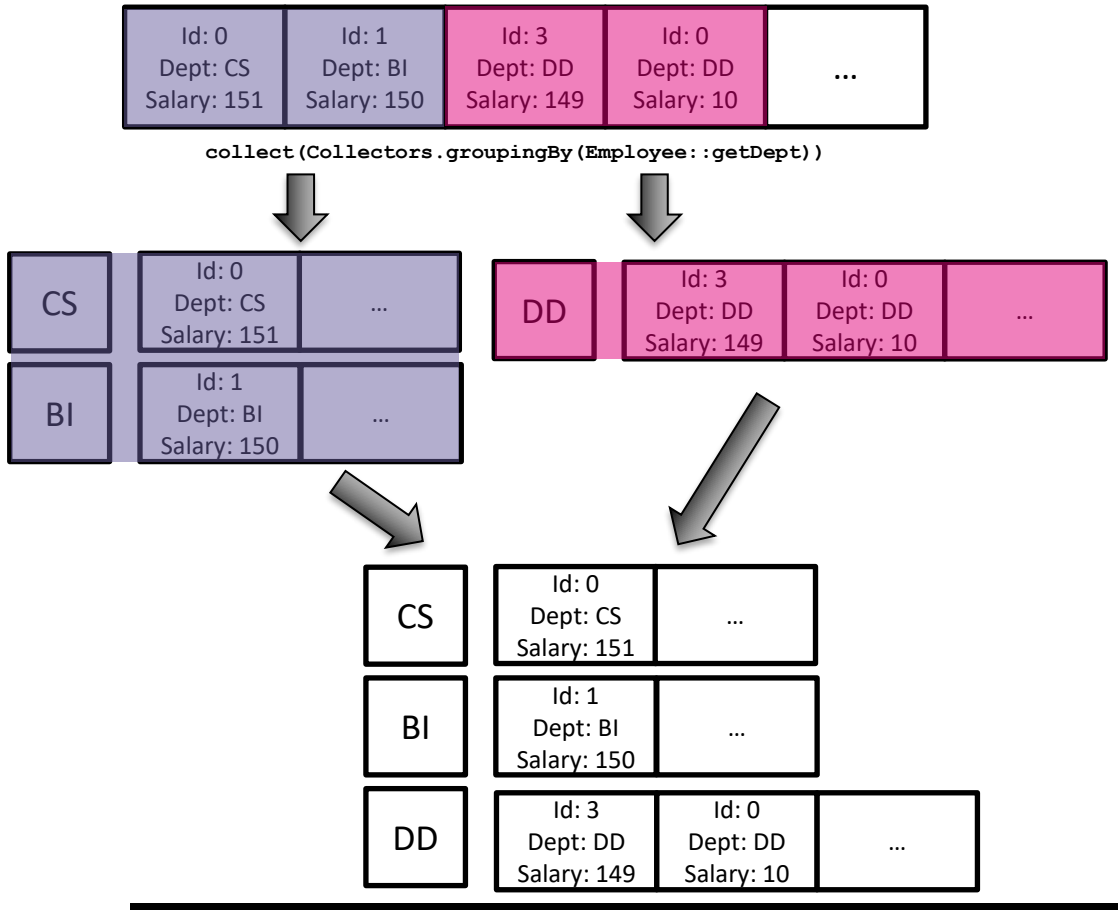


Would it be ok if parallel streams work concurrently on the Map resulting from a groupingBy  operation?

# Java Parallel Streams | Grouping



- In the local reduce operation, each thread creates locally its own “container” (collection or value) for the partial results
- In a final step, a single thread merges the local containers, so no race conditions arise
- However this step is very memory waste full, as it needs to create one container per partition of stream



# Java Parallel Streams | Grouping



- A possible solution is to use **`groupingByConcurrent`**
- This function uses a ConcurrentHashMap that all threads can access concurrently.

```
collect(Collectors.groupingByConcurrent(Employee::getDept))
```

# Counting primes on Java 8 streams



Our old standard Java for loop:

Classical efficient imperative loop

```
int count = 0;
for (int i=0; i<range; i++)
  if (isPrime(i))
    count++;
```

Sequential Java 8 stream:

```
IntStream.range(0, range)
.filter(i -> isPrime(i))
.count()
```

Parallel Java 8 stream:

```
IntStream.range(0, range)
.parallel()
.filter(i -> isPrime(i))
.count()
```

# Counting primes on Java 8 streams



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Sequential Java 8 stream:

Pure functional programming …

```
IntStream.range(0, range)
.filter(i -> isPrime(i))
.count()
```

Parallel Java 8 stream:

```
IntStream.range(0, range)
.parallel()
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```

# Counting primes on Java 8 streams



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Classical efficient imperative loop

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int count = 0;
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```

Sequential Java 8 stream:

Pure functional programming ...

```
IntStream.range(0, range)
.filter(i -> isPrime(i))
.count()
```

Parallel Java 8 stream:

... and thus parallelizable and thread-safe

```
IntStream.range(0, range)
.parallel()
.filter(i -> isPrime(i))
.count()
```

# Performance results



Counting the primes in 2 ... 100.000

Using Mark7

| | | | |
|---|---|---|---|
| Sequential | 4891635.9 ns | 21879.73 | 64 |
| Stream | 4953867.6 ns | 63873.82 | 64 |
| ParallelStream | 1363886.8 ns | 10621.99 | 256 |

Intel i7 (4 cores) speed-up: 3.6 x

# RxJava and the UI



(input) UI elements (buttons, textfields, ...): **observables**

(output) UI elements (textfields, ...): **observers**

Example: RxJava for Android:

```
Button button;  ...
RxView.clicks(button)
  .subscribe(i -> {
        //Perform some work here//
  });
```

https://code.tutsplus.com/tutorials/rxjava-for-android-apps-introducing-rxbinding-and-rxlifecycle--cms-28565?_ga=2.125428746.1281241990.1512099718-1264555618.1502875086

# Observer and Observable



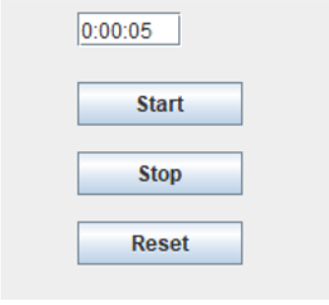
```
Observable.from(letters)
  .map(String::toUpperCase)
  .subscribe(letter -> result += letter);
 assertTrue(result.equals("ABCDEFG"));
```

- *Observable* propagates data from a data source
- An *observer* receives data (via it´s subscribe method)

from https://www.baeldung.com/rx-java

# RxJava version of a Stopwatch






All three buttons must respond to clicking
When started the display must update every second

⇒ 4 streams
- one for each button
- one for handling the clock ticking

```
timer.subscribe(display);
rxPushStart.subscribe(displaysetRunningTrue);
rxPushStop.subscribe(displaysetRunningFalse);
rxPushStart.subscribe(displaysetAllzero);
```

# RxJS (Javascript)



```
const button= document.querySelector("button");
   const observer = {
     next: function(value) {
       ... // handle click
     },
     error: function(err) {   ...   },
     complete: function() {   ...   }
   };

   // Create an Observable from event
   const observable= Rx.Observable.fromEvent(button, "click");
   // Subscribe to begin listening for async result
   observable.subscribe(observer);
```

https://rxjs.dev/guide/overview

# Different types of Observables (2)



Observables can be created in many different ways, e.g.

```
String[] letters= {"a", "b", "c", "d", "e", "f", "g"};
Observable<String> observable= Observable.fromArray(letters);
```

```
List<Integer> list= new ArrayList<>(Arrays.asList(1, 2, 3, 4, 5, 6));
Observable<Integer> observable= Observable.fromIterable(list);
```

```
Observable<Integer> observable= Observable.range(11, 111);
```

```
Observable<Integer> observable= Observable.just(1, 4, 9, 221);
```

https://betterprogramming.pub/rxjava-different-ways-of-creating-observables-7ec3204f1e23

# RxJava Operators



```
Observable<Integer> observable= Observable.range(11, 111).take(10);
```

```
Observable.range(11, 111)
    .filter(i -> (i%2)==0)
    .subscribe(System.out::println);
```

https://github.com/ReactiveX/RxJava/wiki/Alphabetical-List-of-Observable-Operators

# Many subscribers



An observable can have several observes

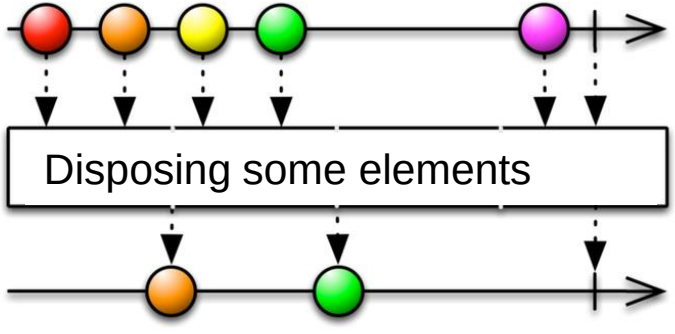
important difference to Java stream !!!

```
rxPush.subscribe(display1);
rxPush.subscribe(display2);
```

# Backpressure




An observable may emit items so fast that the consumer can not keep up, this is called *backpressure*

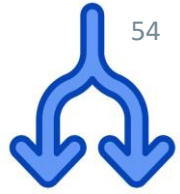



Advice on handling backpressure

https://medium.com/@srinuraop/rxjava-backpressure-3376130e76c1

# RxJava vs Java stream





| RxJava | Java Stream |
| --- | --- |
| push-based | pull-based (terminal operator) |
| many subscribers | one subscriber |
| has rich API | few methods |
| must be added as dependency | built into Java |

https://www.reactiveworld.net/2018/04/29/RxJava-vs-Java-Stream.html

# Reactive programming



Libraries for many languages: Java, .net, JavaScript, ...

ReactiveX website

Nice introduction to RxJava: https://github.com/ReactiveX/RxJava