Practical Concurrent and Parallel Programming X

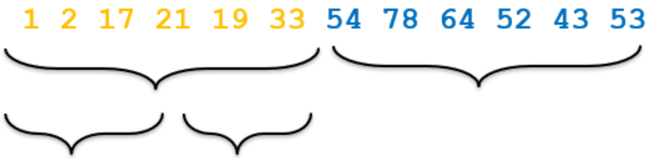
Streams, Parallel Streams and RxJava

Jørgen Staunstrup

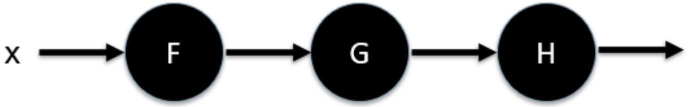
Agenda

- **Java Streams**
- RxJava

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

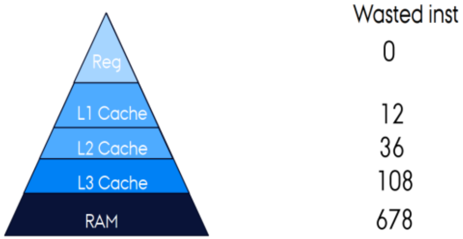


Streams:
Pipeline (different tasks to each thread F, G, H, …)

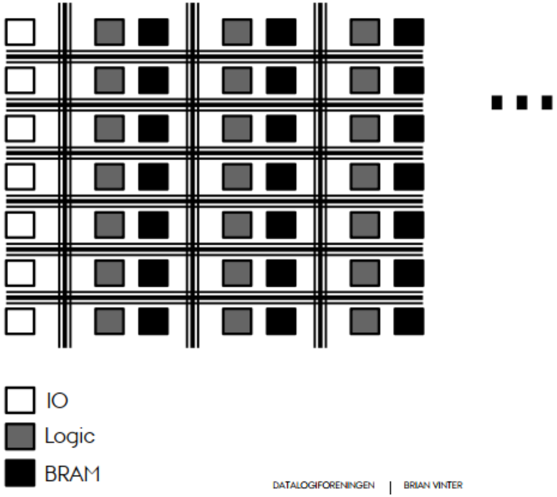


Motivation

Processor @3.3Ghz app 0.1 ns pr instruction
L1 Data Cache Latency = 4 cycles
L2 Cache Latency = 12 cycles
L3 Cache Latency = 36 cycles (3.4 GHz i7-4770)
RAM Latency = 36 cycles + 57 ns (3.4 GHz i7-4770)

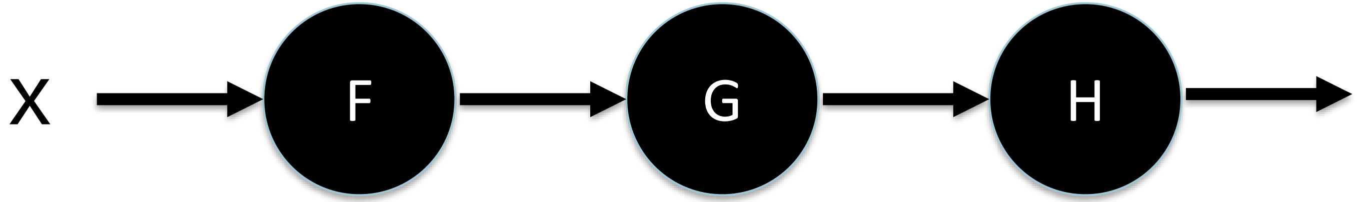


Supercomputer



- Data is often communicated as a stream
- from a file,
- from the internet
- from the user interface
- Reducing memory overhead

Java Stream

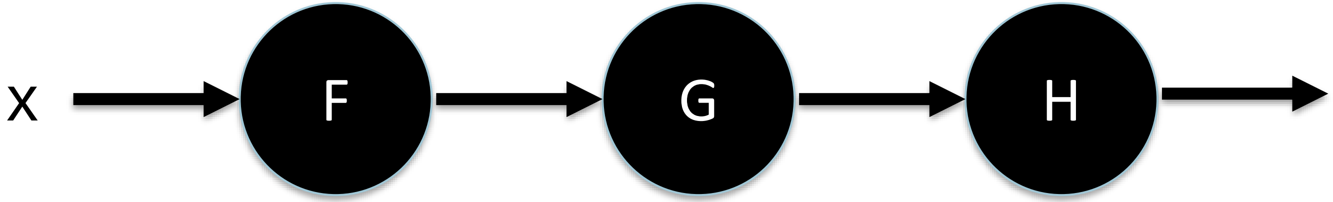


Java Stream

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

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

Stream example



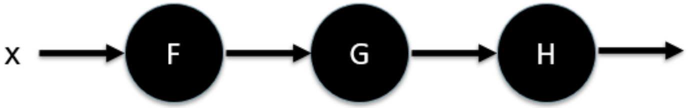
X is a stream of words: ….. ablaut able ableeze … zyme

F discards all words with just one 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
```

Easy to parallelize:

```
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

Java stream

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 collection classes have 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

Section 24

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?

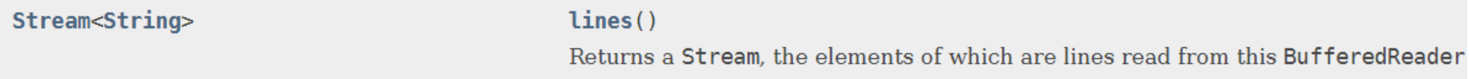
BufferedReader (file)

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() Returns a Stream, the elements of which are lines read from this BufferedReader

BufferedReader (URL)

Exercise: 10.2

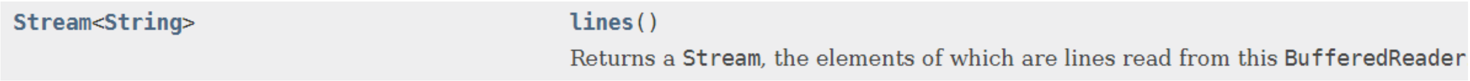
```
String filename = "https://staunstrups.dk/jst/english-words.txt";
System.out.println(readWordsFromURL(urlname).count());


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() 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)

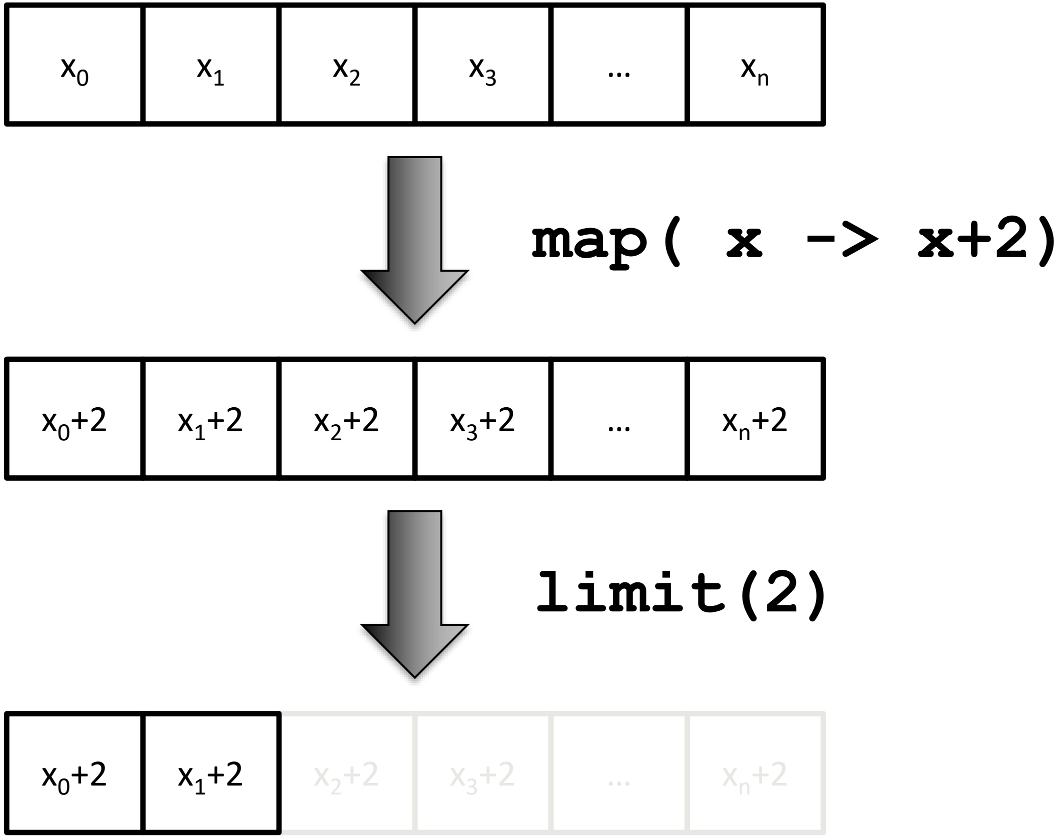
https://howtodoinjava.com/java/stream/java-streams-by-examples/

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



x_0	x_1	x_2	x_3	…	x_n

`map( x -> x+2)`

x_0+2	x_1+2	x_2+2	x_3+2	…	x_n+2

`limit(2)`

x_0+2	x_1+2	x_2+2	x_3+2	…	x_n+2

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

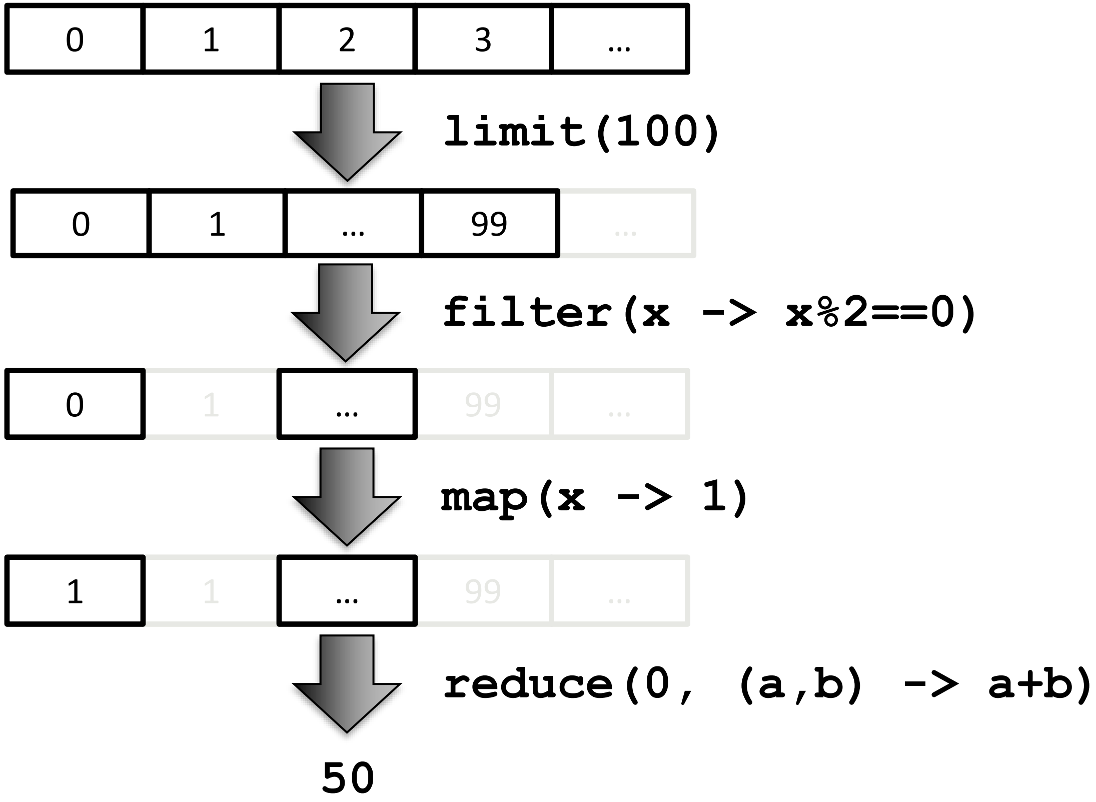
- Reduce can also be called without identity parameter

- 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



0 1 2 3 …

`limit(100)`

0 1 … 99 …

`filter(x -> x%2==0)`

0 1 … 99 …

`map(x -> 1)`

1 1 … 99 …

`reduce(0, (a,b) -> a+b)`

50

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

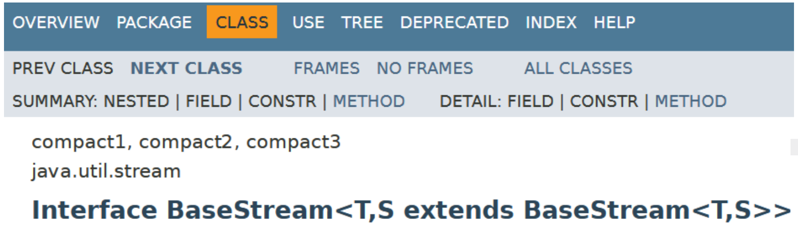
Parallel (intermediate)

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

ordered

`IntStream.range` produces an *ordered* stream

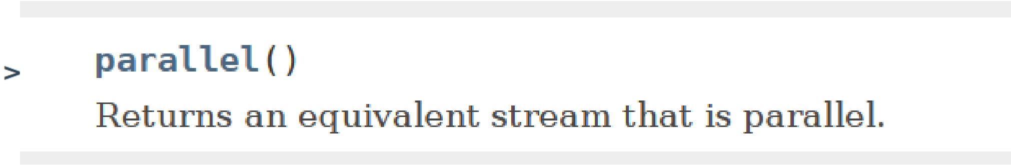
`parallel` is an operation in `BaseStream`



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

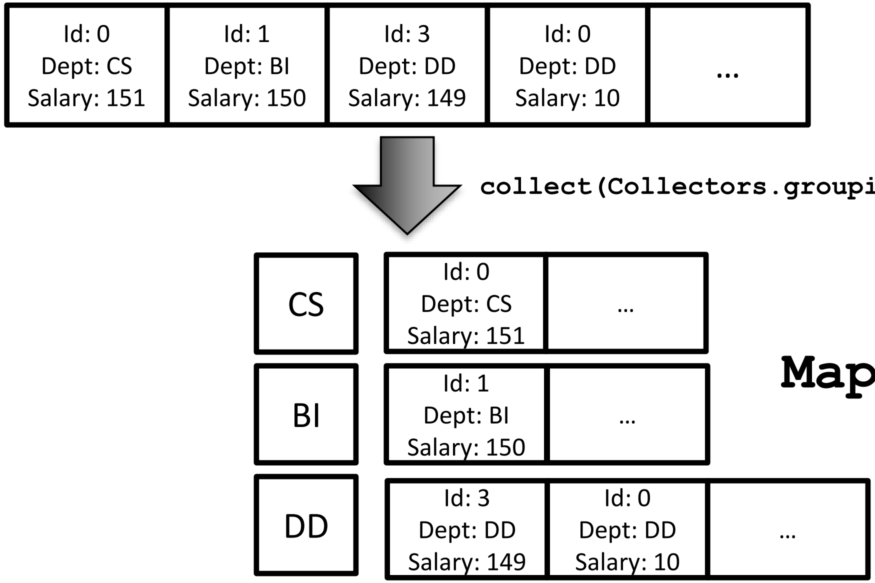
- For instance, converting a stream into a list

```
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));
```



Id: 0 Dept: CS Salary: 151	Id: 1 Dept: BI Salary: 150	Id: 3 Dept: DD Salary: 149	Id: 0 Dept: DD Salary: 10	…

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

CS	Id: 0 Dept: CS Salary: 151	…	
BI	Id: 1 Dept: BI Salary: 150	…	
DD	Id: 3 Dept: DD Salary: 149	Id: 0 Dept: DD Salary: 10	…

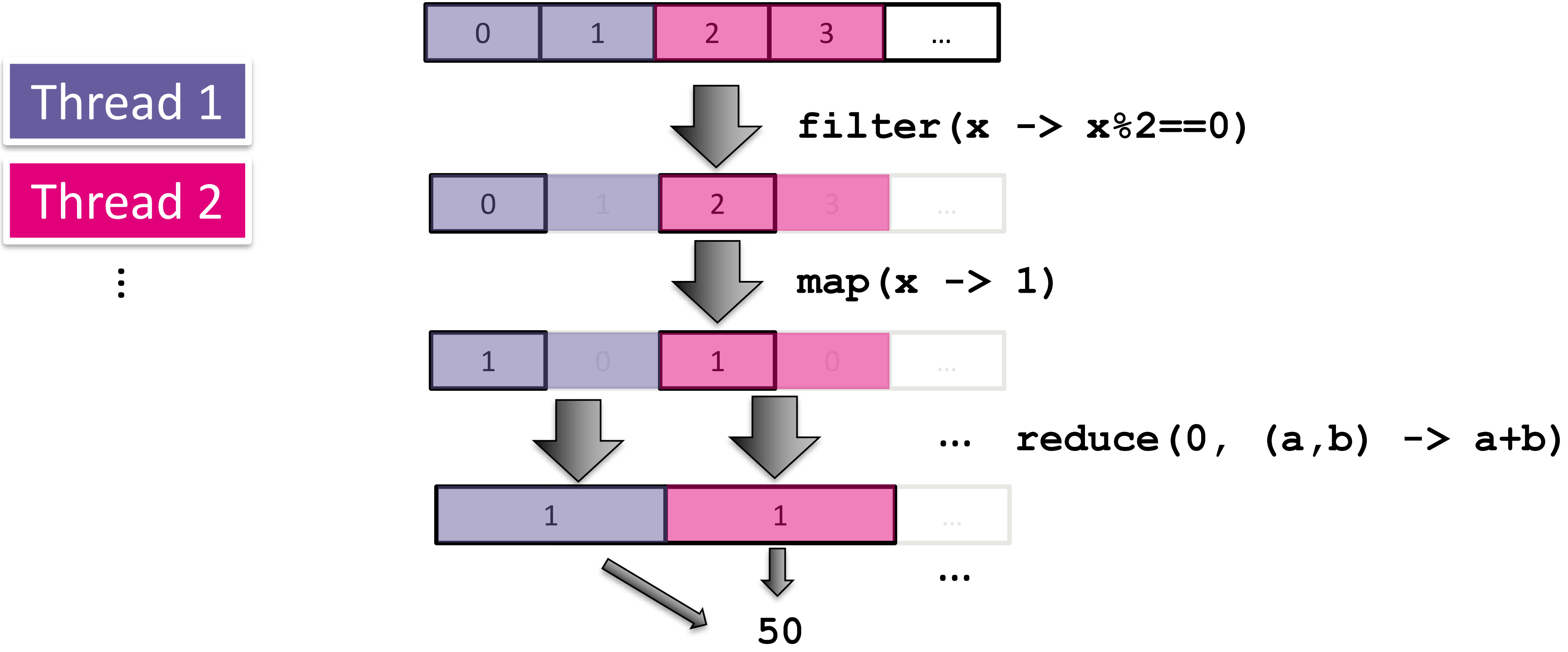
`Map<String,List<Employee>>`

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



```
filter(x -> x%2==0)
map(x -> 1)
reduce(0, (a,b) -> a+b)
```

Java Parallel Streams | Processing order

- Since execution is parallel the processing of the stream is not guaranteed to be 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);`

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

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:

Pure functional programming …

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

Parallel Java 8 stream:

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

PCPP 2019

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:

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
```

PCPP 2019

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

Agenda

- Java Streams
- **RxJava**

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

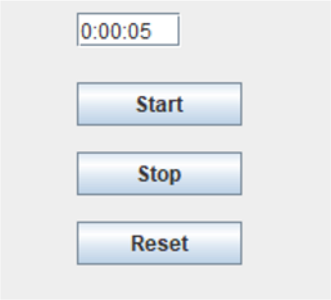
```
Observable.from(letters)
  .map(String::toUpperCase)
  .subscribe(letter -> result += letter);
  assertTrue(result.equals("ABCDEFG"));
```

•*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 observers

- 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

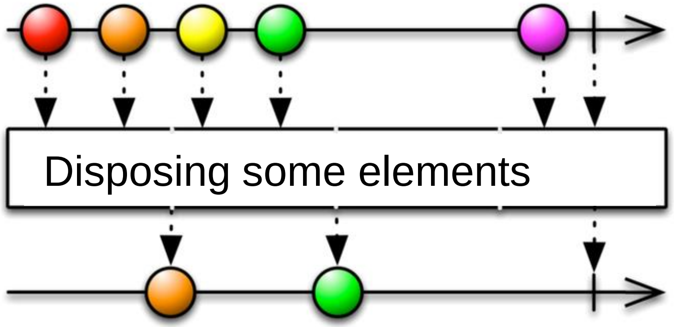
An observable can have several observes

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