

**MAHARISHI UNIVERSITY of MANAGEMENT**

*Engaging the Managing Intelligence of Nature*

**Computer Science Department**

**CS401 Modern Programming  
Practices (MPP)**

**Professor Paul Corazza and  
Professor Ankhtuya Ochirbat**

# Lecture 9: The Stream API

## *Solving Problems by Engaging Deeper Values of Intelligence*

# Wholeness Statement

The stream API is an abstraction of collections that supports aggregate operations like filter and map. These operations make it possible to process collections in a declarative style that supports parallelization, compact and readable code, and processing without side effects. Deeper laws of nature are ultimately responsible for how things appear in the world. Efforts to modify the world from the surface level lead to struggle and partial success. Affecting the world by accessing the deep underlying laws that structure everything can produce enormous impact with little effort. The key to accessing and winning support from deeper laws is going beyond the surface of awareness to the depths within.

# Outline

1. **Introduction to Java 8 Streams**
2. Streams: Basic Facts and a 3-Step Template
3. Different Ways to Create Streams
4. Intermediate Operations on Streams
5. Stateful Intermediate Operations
6. Terminal Operations
7. Working with the Optional class
8. Reduce
9. Collecting Results
10. Primitive Type Streams
11. Stream Reuse and Lambda Libraries

# What Are Streams and Why Are They Used?

1. What They Are. A stream is a way of representing data in a collection (and in a few other data structures) which supports functional-style operations to manipulate the data.

From the API docs: A stream is “a sequence of elements supporting sequential and parallel aggregate operations.”

Streams provide new ways of accessing and extracting data from Collections.

2. Why They Are Used. To understand why they are used, consider the following problem:

*Problem.* Given a list of words (say from a book), count how many of the words have length > 12.

### Imperative-style solution

```
int count = 0;  
for(String word : list) {  
    if(word.length() > 12)  
        count++;  
}
```

#### Issues:

- i. Relies upon shared variable `count`, so is not threadsafe
- ii. Commits to a particular sequence of steps for iteration
- iii. Emphasis is on *how* to obtain the result, not *what* is needed

## **Functional-style solution**

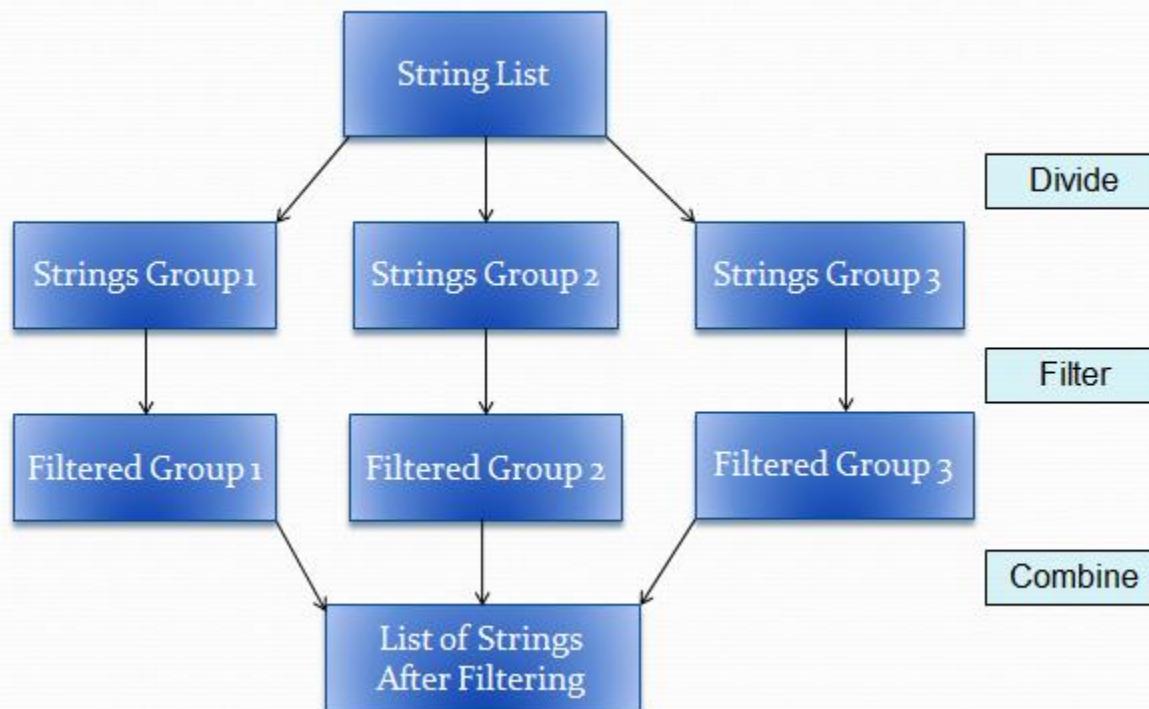
```
final long count  
= words.stream()  
    .filter(w -> w.length() > 12)  
    .count();
```

### Advantages:

- i. Purely functional, so threadsafe
- ii. Makes no commitment to an iteration path, so more parallelizable
- iii. Declarative style – “what, not how”
- iv. With Java 8 it is easy to transform into a parallel processing solution

## Parallel-processing solution

```
final long count  
= words.parallelStream()  
    .filter(w -> w.length() > 12)  
    .count();
```



# Outline

1. Introduction to Java 8 Streams
2. **Streams: Basic Facts and a 3-Step Template**
3. Different Ways to Create Streams
4. Intermediate Operations on Streams
5. Stateful Intermediate Operations
6. Terminal Operations
7. Working with the Optional class
8. Reduce
9. Collecting Results
10. Primitive Type Streams
11. Stream Reuse and Lambda Libraries

# Facts About Streams

1. *Streams do not store the elements they operate on.*  
Typically they are stored in an underlying collection, or they may be generated on demand.
2. *Stream operations do not mutate their source.* Instead, they return new streams that hold the result.
3. *Java Implementation.* The methods on the Stream interface are implemented by the class ReferencePipeline. The method implementations involve a combination of technical operations internal to the stream package.

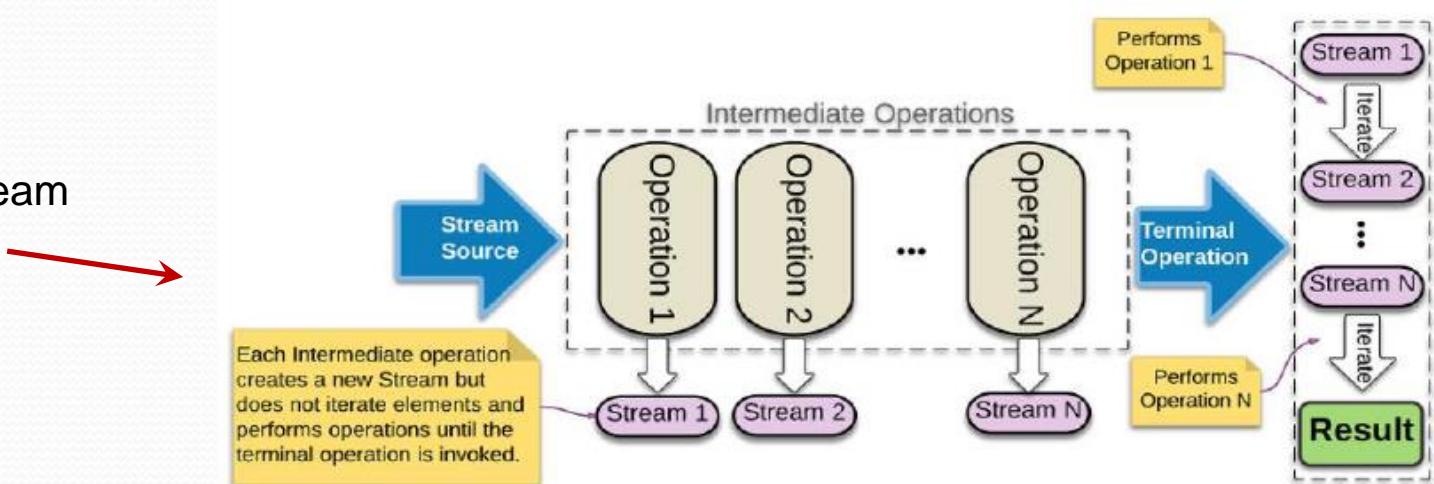
4.

*Stream operations are lazy whenever possible.* Elements in the stream are accessed in a way analogous to streaming video – only the elements that are absolutely necessary are accessed, and the intermediate operations act on those. When more elements are needed, they are accessed. See the demo in lesson9.lecture.lazystream. Diagram below shows **User View**

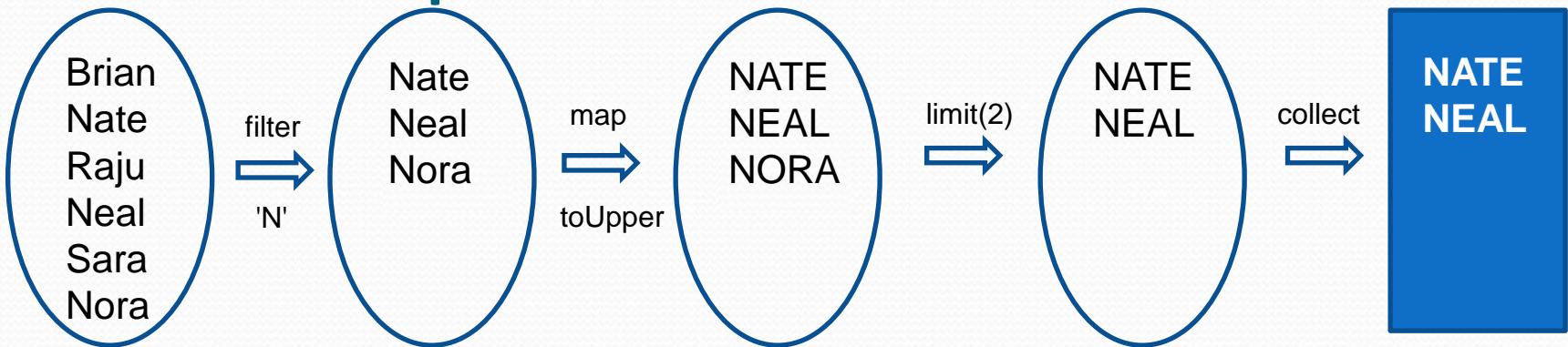
```
public List<String> find(List<String> list,
                           String letter) {
    return list.stream()
        .filter(name -> starts(name,letter))
        .map(name -> toUpper(name))
        .limit(2)
        .collect(Collectors.toList());
}
```

### Stream Lazy Evaluation

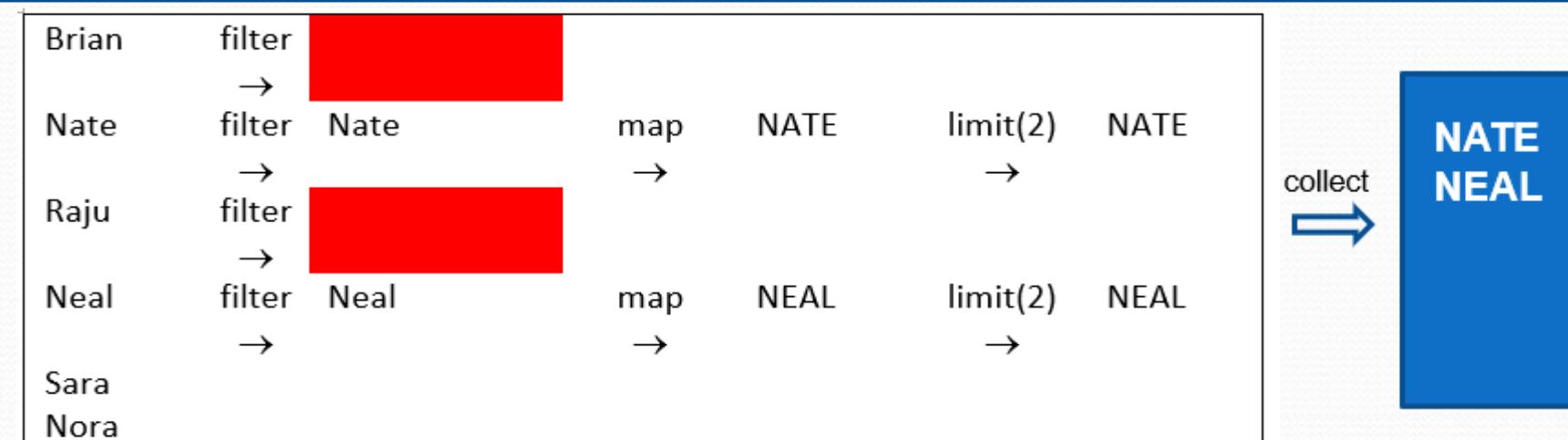
User view of a Stream pipeline



# Stream Pipelines: Under the Hood



User View: New Stream after Each Operation



Under the Hood: *Stream Fusion*.

Loops fused to produce single stream. Demo:  
lesson9.lecture.lazystream.LoopFusion.java

# Template for Using Streams

1. *Create a stream.* Typically, the stream is obtained from some kind of Collection, but streams can also be generated from scratch.
2. *Create a pipeline of operations.* Each of the operations performs some stream transformation and returns a new stream. Called *intermediate operations*.
3. *End with a terminal operation.* The terminal operation produces a result. It also forces lazy execution of the operations that precede it.

Example from Lesson 8:

```
List<String> startsWithLetter =  
    list.stream()                                //create the stream  
        .filter(name -> name.startsWith(letter)) //build pipeline  
        .collect(Collectors.toList());           //invoke terminal operation
```

# Outline

1. Introduction to Java 8 Streams
2. Streams: Basic Facts and a 3-Step Template
3. **Different Ways to Create Streams**
4. Intermediate Operations on Streams
5. Stateful Intermediate Operations
6. Terminal Operations
7. Working with the Optional class
8. Reduce
9. Collecting Results
10. Primitive Type Streams
11. Stream Reuse and Lambda Libraries

# Ways of Creating Streams

1. Obtain a Stream from any Collection object with a call to stream() (this default method was added to the Collection interface in Java 8)
2. Get a Stream from an array of objects using the static of method:

```
Integer[] arrOfInt = {1, 3, 5, 7};  
Stream<Integer> strOfInt = Stream.of(arrOfInt);
```

Cannot do the same for int[]

```
int[] arrOfInt = {1, 3, 5, 7};  
//one-element Stream  
Stream<int[]> strOfInt = Stream.of(arrOfInt);
```

3. Get a Stream from any sequence of arguments: (the of method accepts a varargs argument – for a review of varargs see

<https://docs.oracle.com/javase/1.5.0/docs/guide/language/varargs.html>)

```
Stream<String> song  
= Stream.of("gently", "down", "the", "stream");
```

4. Two ways to obtain *infinite* streams: *generate* and *iterate* (remember stream operations are lazy)

- a. The *generate* function accepts a `Supplier<T>` argument.

In practice, this means that it accepts functions (lambda expressions) with zero parameters.

```
interface Supplier<T> {  
    T get();  
}
```

**Example:** Stream of constant values (“Echo”):

```
Stream<String> echoes = Stream.generate(() -> "Echo");
```

**Example:** Stream of random numbers:

```
Stream<Double> randoms = Stream.generate(Math::random);
```

- b. The `iterate` function accepts a seed value (of type `T`) and a `UnaryOperator<T>` argument.

```
interface UnaryOperator<T> {  
    T apply(T t);  
}
```

**Example:** Stream of natural numbers: (Here, `T` is `Integer`)

```
Stream<Integer> stream2 = Stream.iterate(1, n -> n + 1));
```

(Cannot use `int` in place of `Integer`. We discuss Streams based on primitives later in the lesson)

Demo: `lesson9.lecture.iterate`

# Extracting Substreams and Combining Streams

1. stream.limit(n). The call `stream.limit(n)` returns a new Stream that ends after n elements (or when the original Stream ends if it is shorter). This method is useful for cutting infinite streams down to size.

## Example:

```
Stream<Double> randoms =  
    Stream.generate(Math::random).limit(100);  
// Produces a stream with 100 random numbers.
```

2. stream.skip(n) The call `stream.skip(n)` *discards* the first n elements.

3. `Stream.concat(Stream, Stream)` You can concatenate two streams with the static concat method of the Stream class:

**Example:**

```
Stream<Character> combined =  
    Stream.concat(characterStream("Hello"),  
                  characterStream("World"));  
  
// Produces the Stream  
// ['H', 'e', 'l', 'l', 'o', 'W', 'o', 'r', 'l', 'd']
```

Here is the `characterStream` method – transforms a String into a Stream of Characters:

```
public static Stream<Character> characterStream(String s) {  
    List<Character> result = new ArrayList<>();  
    for (char c : s.toCharArray())  
        result.add(c);  
    return result.stream();  
}
```

# Exercise 9.1

1. Use Stream's iterate method to produce a Stream consisting of all the odd natural numbers 1, 3, 5, . . .
2. Modify your solution so that your Stream consists of exactly these numbers: 9, 11, 13, 15. Print your Stream to the console (somehow)

# Main Point 1

The iterate operation on a Stream makes it possible to generate an infinite sequence of values based on two pieces of data: The initial value, and a rule or principle that tells how one value should be transformed to the next.

The iterate method is an expression of the Principle of Diving. The "correct angle" is the initial value. "Letting go" has the right effect because there is an underlying rule that directs flow from the initial value to subsequent values. During meditation, what guides awareness from one level to the next – the underlying principle or rule – is the gentle pull to move toward what is most charming at each moment while awareness remains lively and awake.

# Outline

1. Introduction to Java 8 Streams
2. Streams: Basic Facts and a 3-Step Template
3. Different Ways to Create Streams
4. **Intermediate Operations on Streams**
5. Stateful Intermediate Operations
6. Terminal Operations
7. Working with the Optional class
8. Reduce
9. Collecting Results
10. Primitive Type Streams
11. Stream Reuse and Lambda Libraries

# Intermediate Operations on Streams:

Use **filter** to Extract a Substream that Satisfies Specified Criteria

- filter accepts as its argument a Predicate<T> interface.

```
interface Predicate<T> {  
    boolean test(T t);  
}
```

Recall the earlier example:

```
final long count = words.stream().filter(  
    w -> w.length() > 12).count();
```

- The return value of filter is another Stream, so filters can be chained:

```
words.stream()  
    .filter(name -> name.contains(" " + c))  
    .filter(name -> !name.contains(" " + d))  
    .filter(name -> name.length() == len)  
    .count();
```

# Intermediate Operations on Streams :

Use **map** to Transform Each Element of a Stream

- **map** accepts a Function interface. Typical special case of the Function interface is

```
interface Function<T, R> {  
    R apply(T t);  
}
```

- A map accepts a Function as input and returns a Stream<R> -- a stream of values each having type R, which is the return type of the Function interface. maps can therefore be chained.
- Example: Given a list List<Integer> list of Integers, obtain a list of Strings representing those Integers (T is Integer, R is String)

```
List<String> strings  
= list.stream().map(x -> x.toString())  
    .collect(Collectors.toList())
```

# Application: Using map with Constructor Method References

1. *Class::new* is a fourth type of method reference, where the method is the *new* operator. Typical translation: *z -> new Class(z)*

## Examples:

- A. **Button::new** - compiler must select which Button constructor to use; determined by context.

When used with *map*, the *Button (String)* constructor would be used, and the constructor reference *Button::new* resolves to the following lambda:

*str -> new Button(str)*

(which realizes a *Function interface*, as required by *map*).

```
List<String> labels = ....;
Stream<Button> stream = labels.stream().map(Button::new);
List<Button> buttons = stream.collect(Collectors.toList());
//Output: a Stream of labeled Buttons, converted to a list
```

.

**B. String::new.** Again, the choice of String constructor depends on context.

```
public class StringCreator {  
    public static void main(String[] args) {  
        Function<char[], String> myFunc = String::new;  
        char[] charArray =  
            {'s','p','e','a','k','i','n','g','c','s'};  
        System.out.println(myFunc.apply(charArray));  
        System.out.println(new String(charArray));  
    }  
}  
//output: speakingcs
```

In this case, `String::new` is short for the lambda expression  
`charArray -> new String(charArray)`,  
which is a realization of the `Function` interface.

See Demo: `lesson9.lecture.newstring`

- C. **int[]::new** is another constructor reference, short for the lambda expression `len -> new int[len]` (where `len` is an integer that is used as the new array length)

## *2. Array constructor reference and the toArray method*

### Problem

```
Stream<String> stringStream = // create Stream  
  
//Can obtain a list of Strings like this  
List<String> stringList = stringStream.collect(Collectors.toList());  
  
//How to obtain an array of Strings? (Not like this!)  
String[] vals = stringStream.toArray(); //compiler error
```

**Solution:** Use a constructor reference to specify the correct type:

```
String[] vals = stringStream.toArray(String[]::new);  
public static void main(String[] args) {  
    List<String> strings  
    ... = Arrays.asList("Eleven", "strikes", "the", "clock");  
    String[] stringArr2 = strings.stream().toArray(String[]::new);  
    System.out.println(Arrays.toString(stringArr2));  
}  
//Output: [Eleven, strikes, the, clock]
```

See Demo: lesson9.lecture.constructorref.GenericArray.

# Exercise 9.2

What is the following code doing? What is the output when it is run?

```
public static void main(String[] args) {
    List<Integer> ints = Arrays.asList(3,5,2,3,8);
    List<int[]> intArrs = ints.stream()
        .map(int[]::new)
        .collect(Collectors.toList());
    List<String> intArrsStr = intArrs.stream()
        .map(Arrays::toString)
        .collect(Collectors.toList());
    System.out.println(intArrsStr);
}
```

# Solution

See lesson9.lecture.constructorref.IntArrayExample

## Main Point 2

Java 8 makes it possible to dynamically construct objects using lambdas or method references. An application of this feature is that a developer can construct an entire Stream of new objects with very little code, by combining map with a constructor method reference.

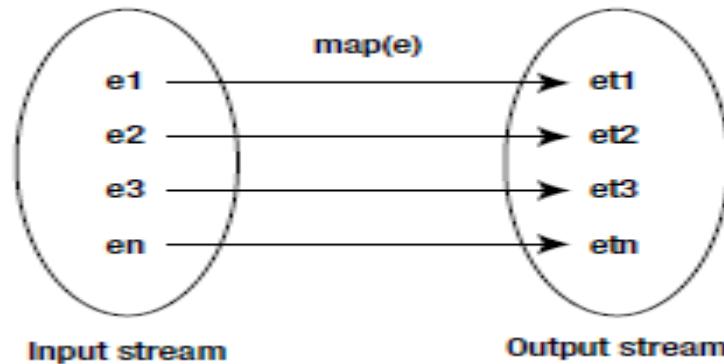
This combination of new Java features reflects a deeper quality that is found in the field of intelligence itself: Intelligence naturally tends toward creative expression.

Contact with our own deepest levels of intelligence through transcending results in enhanced ability for creative expression.

# Intermediate Operations on Streams :

Use **flatMap** to Transform Each Element to a Stream and Flatten the Result

- map operation that facilitates a **one-to-one mapping**. Each element of the input stream is mapped to an element in the output stream.

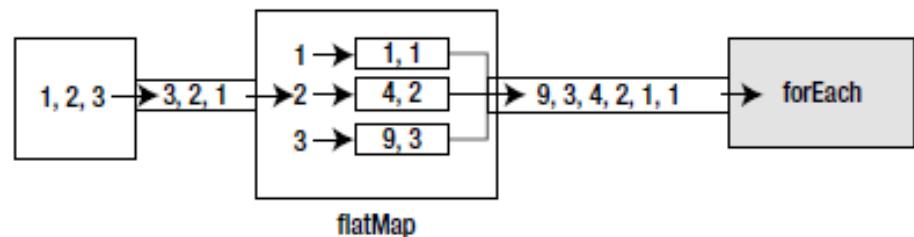


- key **difference between map() vs flatMap() in Java 8:**
  - The function you pass to map() operation returns a single value.
  - The function you pass to flatMap() operation returns a Stream of value.
  - flatMap() is combination of map and flat operation.
  - map() is used for transformation only, but flatMap() is used for both transformation and flattening

# flatMap

- The Streams API also supports **one-to-many** mapping through the flatMap operation
- We illustrate flatMap with an example:  
“Flattening” this Stream means putting all elements together in a single list. This is accomplished using flatMap in place of map:

```
Stream.of(1, 2, 3)
    .flatMap(n -> Stream.of(n, n * n))
    .forEach(System.out::println);
```



# Intermediate Operations on Streams :

Use ***flatMap*** to Transform Each Element to a Stream and Flatten the Result

**Example** Apply the `characterStream` (see earlier slide) to each element of a list, using `map`:

```
List<String> list = Arrays.asList("Joe", "Tom", "Abe");  
Stream<Stream<Character>> result  
    = list.stream().map(s -> characterStream(s))
```

The result Stream is a Stream of Streams:

```
[['J', 'o', 'e'], ['T', 'o', 'm'], ['A', 'b', 'e']] .
```

Typically, we would like to *flatten* the output, to obtain a single Stream of characters.

“Flattening” this Stream means putting all characters together in a single list. This is accomplished using flatMap in place of map:

```
Stream<Character> flatResult  
= list.stream().flatMap(s -> characterStream(s))
```

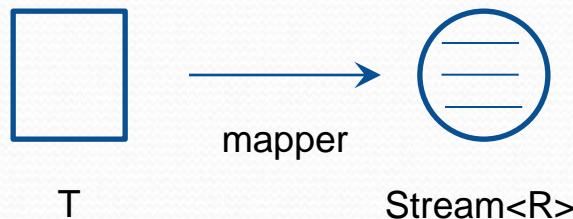
Output:

```
['J', 'o', 'e', 'T', 'o', 'm', 'A', 'b', 'e'].
```

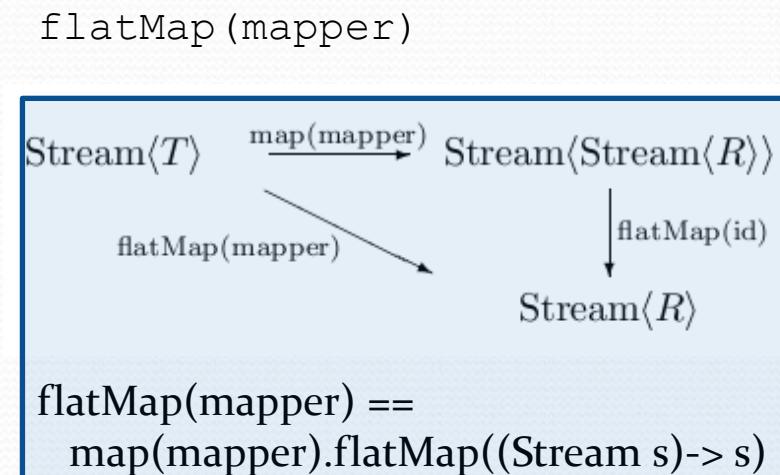
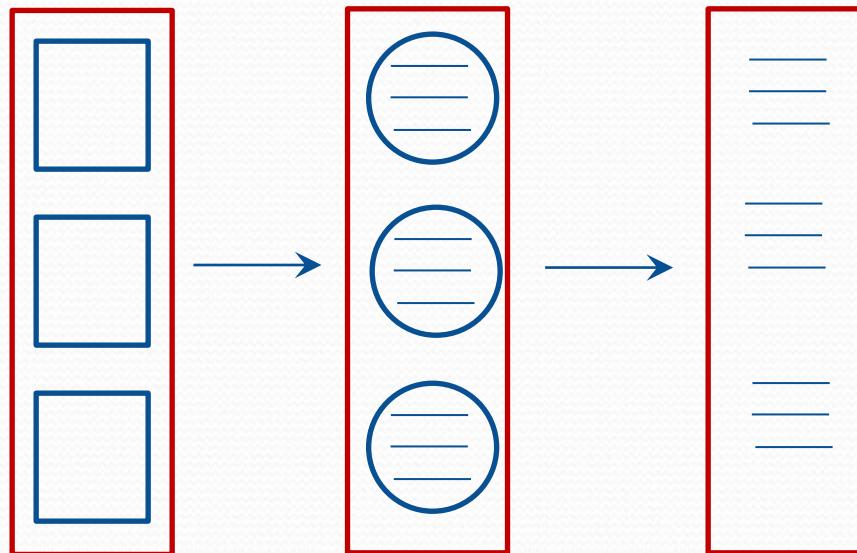
# flatMap

Demo: lesson9.lecture.flatmapstream

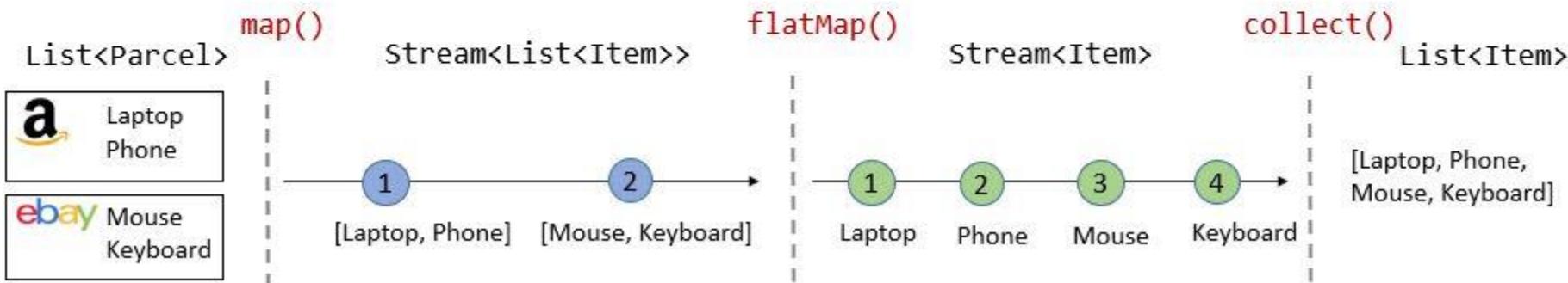
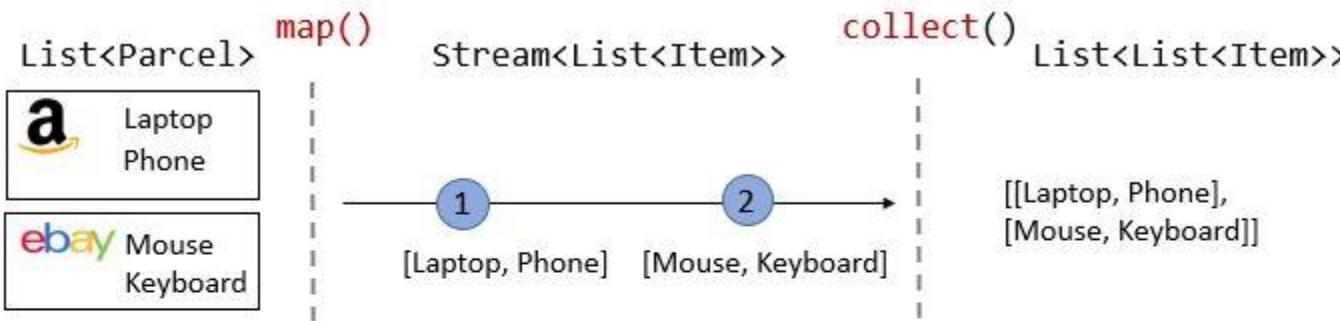
- Start with mapper:  $T \rightarrow \text{Stream}<R>$  (like  $\text{String} \rightarrow \text{Stream}<\text{Character}>$ )



- flatMap transforms a Stream of  $T$ 's first to a Stream of  $\text{Stream}<R>$ 's, and then finally to a Stream of  $R$ 's



# Map FlatMap Difference



# Outline

1. Introduction to Java 8 Streams
2. Streams: Basic Facts and a 3-Step Template
3. Different Ways to Create Streams
4. Intermediate Operations on Streams
5. **Stateful Intermediate Operations**
6. Terminal Operations
7. Working with the Optional class
8. Reduce
9. Collecting Results
10. Primitive Type Streams
11. Stream Reuse and Lambda Libraries

# Stateful Intermediate Operations

1. The transformations discussed so far – map, filter, limit, skip, concat – have been *stateless*: each element of the stream is processed and forgotten. (Recall the "under the hood" view of Streams.)
2. Two *stateful* transformations available from a Stream are distinct and sorted.
3. Example of distinct:

```
Stream<String> uniqueWords  
    = Stream.of("merrily", "merrily", "merrily", "gently")  
        .distinct();  
  
//output: ["merrily", "gently"]
```

#### 4. Example of sorted: (sorted accepts a Comparator parameter)

```
//sort by decreasing lengths of words
List<String> words
    = Arrays.asList("Tom", "Joseph", "Richard");
Stream<String> longestFirst
    = words.stream()
        .sorted((String x, String y) -> y.length()-x.length());
System.out.println(longestFirst.collect(Collectors.toList()));
//output: Richard, Joseph, Tom
```

Demo: lesson9.lecture.comparators1

**Note:** Sorting logic: x comes before y if `y.length() - x.length()` is negative, which happens when x is longer. So "Richard" comes before "Tom"

**Note:** `distinct()` and `sorted()` prevent stream fusion because they are stateful, so pipelines that use these are slightly less efficient

**Note:** This code uses some functional techniques, but notice that the Comparator still has the flavor of “how” rather than “what”.

# Implementing Comparators with More Functional Style

Demo: lesson9.lecture.comparators1

1. In previous example, we are seeking to sort “by String length”, in reverse order. Rather than specifying *how* to do that, we can use the new static comparing method in Comparator:

```
Stream<String> longestFirst =  
    words.stream().sorted(Comparator.comparing(String::length).reversed());
```

2. Comparator.comparing takes a Function<T, U> argument and returns another Comparator.

The type T is the type of the object being compared – in the example, T is String.

The type U is the type of object that will actually be compared - since we are comparing lengths of words, the type U is Integer in this case.

Can now write the call to sort even more intuitively.

```
Function<String, Integer> byLength = x -> x.length();
Stream<String> longestFirst
    = words.stream().sorted(
        Comparator.comparing(byLength).reversed())
```

**Note:** reversed() is a default method in Comparator that reverses the order defined by the instance of Comparator that it is being applied to.

**Note:** The lambda `x -> x.length()` is the same as `String::length`

3. Another example of comparing function: Create a Comparator<Employee> that compares Employees by name, and another that compares by salary

```
Comparator<Employee> NameComparator  
= Comparator.comparing(Employee::getName);
```

```
Comparator<Employee> SalaryComparator  
= Comparator.comparing(Employee::getSalary);
```

## 4. Support for Comparators that are *consistent with equals*.

Demo: lesson9.lecture.comparators2  
(Recall consistency with equals issue in Lab 8)

Recall when we wanted to sort Employees (where an Employee has a name and a salary) by name, we needed to consider also the salary, or else the Comparator is not consistent with equals – the following Comparator, passed to Collections.sort, is not consistent with equals

```
Collections.sort(emps, (e1, e2) -> {
    if (method == SortMethod.BYNAME) {
        return e1.name.compareTo(e2.name);
    } else {
        if (e1.salary == e2.salary) return 0;
        else if (e1.salary < e2.salary) return -1;
        else return 1;
    }
}) ;
```

- This approach is “how”-oriented, and can be made more declarative by using the `comparing` and `thenComparing` methods of `Comparator`. At the same time, we make it consistent with `equals`

```
Function<Employee, String> byName = e -> e.getName();
Function<Employee, Integer> bySalary = e -> e.getSalary();
```

```
public void sort(List<Employee> emps, final SortMethod method) {
    if(method == SortMethod.BYNAME) {
        Collections.sort(emps, Comparator.comparing(byName).thenComparing(bySalary));
    } else {
        Collections.sort(emps, Comparator.comparing(bySalary).thenComparing(byName));
    }
}
```

## Notes about comparing and thenComparing:

- comparing is a static method of Comparator, and therefore cannot be chained
- thenComparing is a default method that also accepts a function of type Function<T, U>; being a default method, it can be chained. It modifies current Comparator by applying its compare method just when the current compare method returns 0.

# Exercise 9.3

Use the comparing and thenComparing methods of Comparator to sort a list of Accounts first by balance, then by ownerName. See lesson9.exercise\_3 in the InClassExercises project.

```
public class Account {  
    private String ownerName;  
    private int balance;  
    private int acctId;  
    public Account(String owner, int bal, int id) {  
        ownerName = owner;  
        balance = bal;  
        acctId = id;  
    }  
}
```

# Solution

```
List<Account> sorted  
= accounts.stream()  
    .sorted(Comparator.comparing((Account a) -> a.getBalance())  
           .thenComparing(a -> a.getOwnerName()))  
    .collect(Collectors.toList());
```

# Main Point 3

The `comparing` and `thenComparing` methods are examples of the new declarative style that can be used in working with Streams in Java 8. This style of programming makes it possible to obtain results simply by *declaring* what is needed, rather than specifying in detail *how* to obtain the results. In a similar way, as awareness becomes more and more familiar with its unbounded transcendental value, we are able to achieve goals with less effort, because transcending engages the deeper levels of nature's functioning, winning support for our individual intentions.

# Outline

1. Introduction to Java 8 Streams
2. Streams: Basic Facts and a 3-Step Template
3. Different Ways to Create Streams
4. Intermediate Operations on Streams
5. Stateful Intermediate Operations
6. **Terminal Operations**
7. Working with the Optional class
8. Reduce
9. Collecting Results
10. Primitive Type Streams
11. Stream Reuse and Lambda Libraries

# Terminal Operations on Stream

1. The last step in a pipeline of Streams is an operation that produces a final output – such operations are called *terminal operations* because, once they are called, the stream can no longer be used.

They are also called *reduction methods* because they reduce the stream to some final value.

We have already seen one example:

```
collect(Collectors.toList())
```

2. *count*: Counts the number of elements in a Stream.

```
List<String> words = //...
int numLongWords
    = words.stream()
        .filter(w -> w.length() > 12)
        .count();
```

# Terminal Operations

3. *max, min, findFirst, findAny* search a stream for particular values and will throw an exception if not handled properly. An easy way to handle:

**Example:** max

```
Optional<String> largest = words.stream()
    .max(String::compareToIgnoreCase);
if (largest.isPresent())
    System.out.println("largest: " + largest.get());
```

An `Optional` is a wrapper for the answer – either the found `String` can be read via `get()`, or a boolean flag can be read that says no value was found (for example, if the stream was empty).

You can call `get()` on an `Optional` to retrieve the stored value, but if the value was not found, so that the `Optional` flag `isPresent` is false, calling `get()` produces a `NoSuchElementException`.

# Terminal Operations

**Example:** `findFirst`

```
Optional<String> startsWithQ  
    = words.stream()  
        .filter(s -> s.startsWith("Q"))  
        .findFirst();
```

**Example:** `findAny` This operation returns an `Optional` that contains some value in an input Stream. (How this value is chosen from the Stream is not guaranteed.) If the Stream is empty, the returned `Optional` is empty. This operation works much better with parallel Streams than `findFirst`.

```
Optional<String> startsWithQ  
    = words.parallelStream()  
        .filter(s -> s.startsWith("Q"))  
        .findAny();
```

# Outline

1. Introduction to Java 8 Streams
2. Streams: Basic Facts and a 3-Step Template
3. Different Ways to Create Streams
4. Intermediate Operations on Streams
5. Stateful Intermediate Operations
6. Terminal Operations
7. Working with the Optional class
8. **Reduce**
9. Collecting Results
10. Primitive Type Streams
11. Stream Reuse and Lambda Libraries

# Terminal Operations continued: The reduce Operation

- The `reduce` operation lets you combine the terms of a stream into a single value by repeatedly applying an operation.

**Example** We wish to sum the values in a list `digits` of numbers.

Procedural code:

```
int sum = 0;  
for(int x : digits) {  
    sum += x;  
}
```

Using the `reduce` operation, the code looks like this:

```
Integer sum2 = digits.stream().reduce(0, (x, y) -> x + y);
```

# The reduce Operation (cont.)

```
digits.stream().reduce(0, (x, y) -> x + y)
```

- *First Argument: Initial Value.* First argument is the initial value; it is the value that is returned if the stream is empty and is the starting point for the computation. It is also (or *should be*) the *identity element* for the combining operation.
- *Second Argument:* A lambda of type `BinaryOperator<T>`.

```
interface BinaryOperator<T> {  
    T apply(T a, T b);  
}
```

- *The Computation.* The computation starts by applying the binary operator to the pair  $(e, f)$ , where  $e$  is the initial value (0 in this example) and  $f$  is the first element of the stream, producing `accum`. Then the binary operator is applied to  $(\text{accum}, g)$  where  $g$  is the next element in the stream, and the result is stored in `accum` again. This continues until all stream values have been used.

- When the stream consists of numbers and the binary operator is ordinary addition, the output is the sum of all the numbers in the stream. If the stream is empty, the initial value is returned – note that the sum of an empty collection of numbers is by convention 0.
- Example.** Start with the following stream:  $[2, 1, 4, 3]$ , and use ordinary addition for the `BinaryOperator` functor. Then the `reduce` method performs the following computation:

$$(((0 + 2) + 1) + 4) + 3 = 10$$

- A parallel computation can improve performance. Say  $[2, 1, 4, 3]$  is broken up into  $[2, 3], [4, 1]$ . Then in parallel we arrive at the same answer in the following way:

$$\begin{aligned} \text{sum1} &= (0 + 2) + 3 & \text{sum2} &= (0 + 4) + 1 \\ \text{combined} &= \text{sum1} + \text{sum2} = 10 \end{aligned}$$

# The reduce Operation (cont.)

- **Question:** How could we form the *product* of a list of numbers?
- **Answer:** We form the product of a list numbers of Integers. For the initial value, we ask, "What is the identity element for the multiplication operation?" The identity is 1. (**Note** that, by convention, the product of an empty list of numbers is 1.)

Here is the line of code that does the job:

```
int product = numbers.stream().reduce(1, (x, y) -> x * y);
```

# The reduce Operation (cont.)

- Example. What about subtraction? What happens when the following line of code is executed? Try it when numbers is the list [2, 1, 4, 3].

```
int difference=numbers.stream().reduce(0, (a, b) -> a - b);
```

- Here, the computation proceeds like this:

$$((0 - 2) - 1) - 4 \quad //\text{output: } -10$$

- The problem here is that performing this computation in parallel gives a different result; subtractions are grouped differently for a parallel computation. For instance, during parallel computation, if [2, 1, 4, 3] is broken up into [2, 3] and [4, 1], the computation would look like this:

$$\text{diff1} = (0 - 2) - 3 \quad \text{diff2} = (0 - 1) - 4$$
$$\text{combined} = \text{diff1} - \text{diff2} = 0$$

- For this reason, not only should the initial value be an identity element (it isn't an identity for subtraction) but also:

*Use reduce only on operations that are commutative and associative.*

(Note that + and \* are commutative & associative, but subtraction is not.)

See the demo lesson9.lecture.reduce.

# The reduce Operation (cont.)

- The reduce method has an overloaded version with only one argument.
- Continuing with the sum example, here is a computation with the overridden version:

```
Optional<Integer> sum  
= Stream.of(digits).reduce((x, y) -> x + y);
```

- This version of `reduce` produces the same output as the earlier version *when the stream is nonempty*, but it is stored in an `Optional` in this case. When the stream is empty, the `reduce` operation returns a `null`, which is again embedded in an `Optional`.

# Exercise 9.4

Use reduce to concatenate the Strings in the Stream below to form a single, space-separated String. Print the result to the console. See lesson9.exercise\_4 in the InClassExercises project.

```
public static void main(String[] args) {  
    Stream strings = Stream.of("A", "good", "day", "to", "write", "some", "Java");  
}
```

# Main Point 4

When a Collection is wrapped in a Stream, it becomes possible to rapidly make transformations and extract information in ways that would be much less efficient, maintainable, and understandable without the use of Streams. In this sense, Streams in Java represent a deeper level of intelligence inherent in the concept of “collection” that has been implemented in the Java language.

When intelligence expands, challenges and tasks that seemed difficult and time-consuming before can become effortless and meet with consistent success. This is one of the documented benefits of TM practice.

# Outline

1. Introduction to Java 8 Streams
2. Streams: Basic Facts and a 3-Step Template
3. Different Ways to Create Streams
4. Intermediate Operations on Streams
5. Stateful Intermediate Operations
6. Terminal Operations
7. **Working with the Optional class**
8. Reduce
9. Collecting Results
10. Primitive Type Streams
11. Stream Reuse and Lambda Libraries

# Working with Optional

## *– A Better Way to Handle Nulls*

1. The previous slide introduced the `Optional` class. `Optional` was added to Java to make handling of nulls less error prone. However notice

```
if (optionalValue.isPresent())
    optionalValue.get().someMethod();
```

is no easier than

```
if (value != null)
    value.someMethod();
```

The `Optional` class, however, supports other techniques that are superior to checking nulls.

# Working with Optional

## orElse

2. The `orElse` method – if result is null, provides alternative output using `orElse`

```
//OLD WAY
public static void pickName(final List<String> names, final String startingLetter) {
    String foundName = null;
    for (String name : names) {
        if (name.startsWith(startingLetter)) {
            foundName = name;
            break;
        }
    }
    System.out.print(String.format("A name starting with %s: ", startingLetter));
    if (foundName != null) {
        System.out.println(foundName);
    } else {
        System.out.println("No name found");
    }
}
```

```
//NEW WAY
public static void pickName(final List<String> names, final String startingLetter) {
    final Optional<String> foundName = names.stream()
        .filter(name -> name.startsWith(startingLetter))
        .findFirst();
    System.out.println(
        String.format("A name starting with %s: %s",
            startingLetter,
            foundName.orElse("No name found")));
}
```

The `orElse` method on an `Optional` returns the value stored in the `Optional`, if present. If not present, returns the alternative value supplied as an argument to `orElse`.

The alternative value supplied must have the same type as the value stored in the original `Optional`.

# Working with Optional

## ifPresent(Consumer)

3. Use ifPresent (Consumer) to invoke an action and skip the null case completely. (This is an overloaded version of ifPresent)

```
public static void pickName(List<String> names, String
    startingLetter) {

    final Optional<String> foundName
        = names.stream()
            .filter(name -> name.startsWith(startingLetter))
            .findFirst();

    foundName.ifPresent(
        name -> System.out.println("Hello " + name));
}
```

**Note:** If the name is found, it is printed to the console; if not, nothing happens.

# Creating Your Own Optionals

- **Using `of` and `empty`.** You can create an `Optional` instance in your own code using the static method `of`. However, if `of` is used on a null value, a `NullPointerException` is thrown, so the best practice is to use `of` together with `empty`, as in the following:

```
public static Optional<Double> inverse(Double x) {  
    return x == 0 ? Optional.empty() : Optional.of(1/x);  
}
```

`Optional.empty()` creates an `Optional` with no wrapped value; in that case, the `isPresent` flag is set to false.

# Creating Your Own Optionals - Continued

- **Using `ofNullable`.** The static method `ofNullable` lets you read in a possibly null value. In particular, `ofNullable` returns an `Optional` that embeds the specified value if non-null, otherwise returns an empty `Optional`.
- Can use `orElse/orElseGet` together with `Optional.ofNullable`.
- **Example.** Here, `readInput()` returns either null or a person's name.

```
void createOutput() {  
    String outputMessage = "Hello ";  
    outputMessage  
        += Optional.ofNullable(readInput()).orElse("World!");  
    return outputMessage;  
}
```

# ofNullable used with orElse/orElseGet

When you wish to obtain a value from a method call using `orElse`, use `orElseGet` instead.

- **Example.** Use `orElseGet` as a way to implement a lazy singleton. The following is an example in which a `Connection` object (JDBC) is accessed lazily within a `ConnectionManager` class.

`lesson5.lecture.factorymethods3.dataaccess.DataAccessSubsystem`

```
private static Connection conn = null;
private static Connection createConnection() {
    try {
        conn = DriverManager.getConnection(DB_URL, USERNAME, PASSWORD);
        return conn;
    } catch(SQLException e) {
        throw new RuntimeException(e);
    }
}
public static Connection getConnection() {
    return Optional.ofNullable(conn).orElseGet(ConnectManager::createConnection);
}
```

# orElseGet Syntax

- orElseGet expects an instance of Supplier as input

```
interface Supplier<T> {  
    T get();  
}
```

# Difference Between orElse and orElseGet

- *Warning.* If `orElse` to call a method and use the return value, even if `ofNullable` encounters a non-null input, the method call in `orElse` will still execute, but the return value is ignored. (This is usually undesirable)

In the code on previous slide, if we write instead

```
public Connection getConnection() {  
    return Optional.ofNullable(conn).orElse(myGetConn());  
}
```

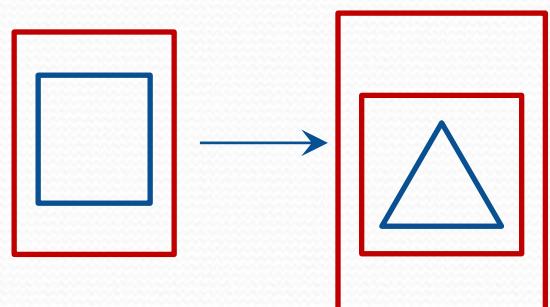
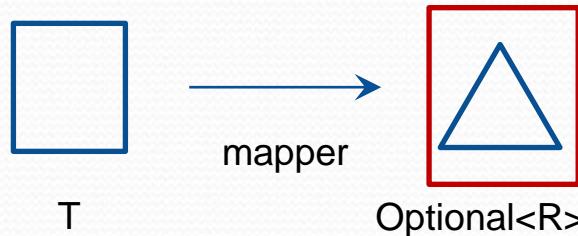
then, when `conn` is not null, `orElse` will cause `myGetConn()` to be invoked, but will ignore its return value and return `conn` instead.

In the same scenario, the following code will *not* cause `myGetConn()` to be invoked when `conn` is not null.

```
public Connection getConnection() {  
    return Optional.ofNullable(conn).orElseGet(() ->  
        myGetConn());  
}
```

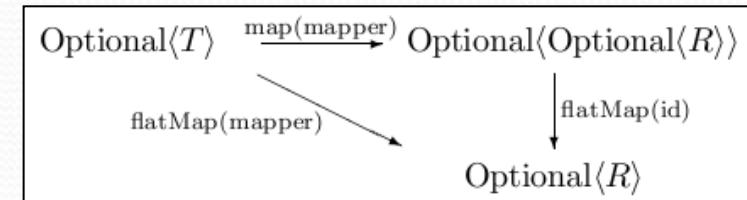
# Using Optional : flatMap

The `flatMap` method works the same way as it does on `Stream`. It allows you to chain method calls and skip null checks. Given a mapper from type `T` to an `Optional<R>`, `flatMap` transforms an `Optional<T>` first to an `Optional<Optional<R>>`, then to an `Optional<R>`



`Optional<T>`      `Optional<Optional<R>>`      `Optional<R>`

`flatMap (mapper)`



# Example of Optional's flatMap

Problem: At most one company is a winner in a multi-company contest. The winning company will have one or more employees with a winning ticket. Find the primary telephone number of the employee with the biggest winnings.

## Imperative Solution

```
private static String telNumberOfBiggestWinnerImperative(List<Company> list) {  
    boolean winningCompanyFound = false;  
    for(Company c: list) {  
        if(c.hasWinningTicket()) {  
            winningCompanyFound = true;  
            int largestSoFar = 0;  
            Employee biggestWinner = null;  
            List<Employee> emps = c.getEmployees();  
            for(Employee e: emps) {  
                int wins = e.getWinningAmount();  
                if(wins > largestSoFar) {  
                    largestSoFar = wins;  
                    biggestWinner = e;  
                }  
            }  
            List<String> telNums = biggestWinner.getTelephoneNumbers();  
            if(telNums != null && telNums.size() > 0)  
                return telNums.get(0);  
            else  
                return "Winner has no phone number";  
        }  
    }  
    if(!winningCompanyFound) {  
        return "No winning company";  
    }  
    return null;  
}
```

## Solution with flatMap and Optional

```
static Comparator<Employee> winnings
= Comparator.comparing((Employee e) -> e.getWinningAmount());

private static String telNumberOfBiggestWinner(List<Company> list) {
    return list.stream().filter((Company c) -> c.hasWinningTicket())
        .findAny()
        .flatMap((Company c) -> c.getEmployees().stream().max(winnings))
        .flatMap((Employee e) -> e.getTelephoneNumbers().stream().findFirst())
        .orElse("Not found");
}
```

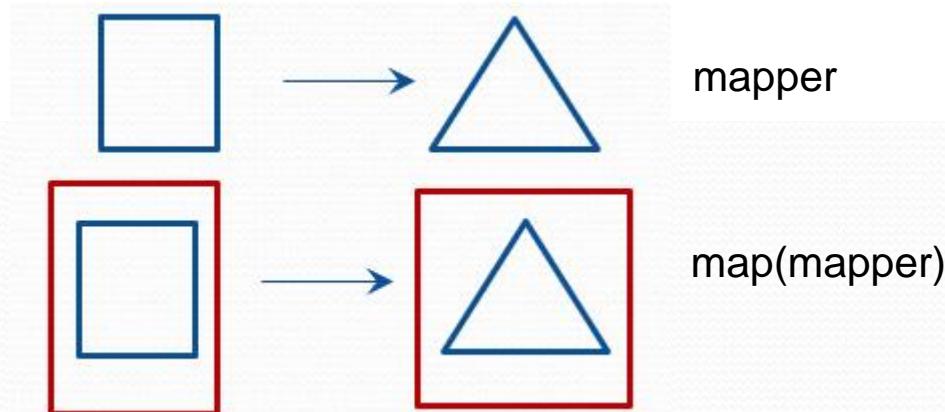
# Example: Replacing null checks with Optional

Consider imperative code for seeing if a Person from Fairfield can be found in a list of Persons:

```
private static boolean personFromFairfield(List<Person> persons) {  
    Person foundPerson = null;  
    for(Person p: persons) {  
        if(p != null) {  
            Address addr = p.getAddress();  
            if(addr != null) {  
                String city = addr.getCity();  
                if(city != null) {  
                    if(city.equals("Fairfield")) {  
                        foundPerson = p;  
                    }  
                }  
            }  
        }  
    }  
    return foundPerson != null;  
}
```

- Using Optionals with map completely eliminates these (unnecessary) null checks

```
private static boolean personFromFairfield(List<Person> persons) {
    for(Person p: persons) {
        if(Optional.ofNullable(p).map(x -> x.getAddress())
            .map(x->x.getCity())
            .orElse("").equals("Fairfield")) {
            return true;
        }
    }
    return false;
}
```



- Notes.

- If an Optional opt is empty, opt.map(mapper) returns an empty Optional
- See lesson9.lecture.optional\_map.usingsoptionals

# Outline

1. Introduction to Java 8 Streams
2. Streams: Basic Facts and a 3-Step Template
3. Different Ways to Create Streams
4. Intermediate Operations on Streams
5. Stateful Intermediate Operations
6. Terminal Operations
7. Reduce
8. Working with the Optional class
9. **Collecting Results**
10. Primitive Type Streams
11. Stream Reuse and Lambda Libraries

# Collecting Results

- One kind of terminal operation in a stream pipeline is a *reduction* that outputs a single value, like `max` or `count` or `reduce`. Another kind of terminal operation collects the elements of the Stream into some type of collection, like an array, list, or map. We have seen examples already.

**Example:** Collecting into an array

```
String[] result = stream.toArray(String[]::new);
```

**Example:** Collecting into a List

```
List<String> result = stream.collect(Collectors.toList());
```

**Example:** Collecting into a Set

```
Set<String> result = stream.collect(Collectors.toSet());
```

**Example:** Collecting into a particular kind of Set (same idea for particular kinds of lists, maps)

```
TreeSet<String> result =
    stream.collect(Collectors.toCollection(TreeSet::new));
```

# Collecting Results (cont.)

**Example** Collect all strings in a stream by concatenating them:

```
String result = stream.collect(Collectors.joining());
```

//separates strings by commas

```
String result = stream.collect(Collectors.joining(", "));
```

//prepares objects as strings before joining

```
String result = stream.map(Object::toString)
    .collect(Collectors.joining(", "));
```

**Note:** Here instead of `Object::toString` you can use your own object type, like `Employee::toString`. By polymorphism, either way works. See demo lesson9.lecture.collect

# Collecting Results (cont.)

Example Collecting into a map – two typical examples.

Here, `personStrm` is a Stream of Person objects.

//key = id, value = name

```
Map<Integer, String> idToName =
    personStrm.collect(Collectors.toMap(Person::getId,
                                         Person::getName));
```

//key = id, value = the person object

```
Map<Integer, Person> idToPerson =
    personStrm.collect(Collectors.toMap(Person::getId,
                                         Function.identity()));
```

Note: `identity` is a static method on `Function` that returns a function that always returns its input argument. In the example, it is the function

$(\text{Person } p) \rightarrow p$

# Collecting Results (cont.)

- Can collect “summary statistics” for Streams whose elements can be mapped to ints. IntSummaryStatistics provides sum, average, maximum, and minimum

```
IntSummaryStatistics summary =  
    words.collect(Collectors.summarizingInt(String::length));  
double averageWordLength = summary.getAverage();  
double maxWordLength = summary.getMax();  
  
//Recall: String::length means str -> str.length()
```

- Similar SummaryStatistics classes are available for Double and Long types too:
  - DoubleSummaryStatistics uses Collectors.summarizingDouble
  - LongSummaryStatistics uses Collectors.summarizingLong.

- **Note:** IntSummaryStatistics extracts int information from an input Stream. The elements of the Stream will therefore be converted at runtime to (primitive) ints in order for summarizingInt to perform its tasks.
- The summarizingInt method expects an argument that is an implementation of theToIntFunction<T> interface:

```
interface ToIntFunction<T> {  
    int applyAsInt(T value);  
}
```

# Exercise 9.5

Use DoubleSummaryStatistics to output to the console the top test score, lowest test score, and average among all test scores in a given list. See lesson9.exercise\_5 in InClassExercises project.

```
public class ExamData {  
    private String studentName;  
    private double testScore;  
    public ExamData(String name, double score) {  
        studentName = name;  
        testScore = score;  
    }  
}
```

```
public static void main(String[] args) {  
    List<ExamData> data = new ArrayList<ExamData>();  
    {  
        add(new ExamData("George", 91.3));  
        add(new ExamData("Tom", 88.9));  
        add(new ExamData("Rick", 80));  
        add(new ExamData("Harold", 90.8));  
        add(new ExamData("Ignatius", 60.9));  
        add(new ExamData("Anna", 77));  
        add(new ExamData("Susan", 87.3));  
        add(new ExamData("Phil", 99.1));  
        add(new ExamData("Alex", 84));  
    }  
};  
}
```

# Collecting Results (cont.)

- `groupingBy` is a static method of `Collectors` class in Java are used for grouping objects by some property and storing results in a `Map` instance.

```
// Group employees by department
```

```
Map<String, List<Person>> byCity = persons.stream()
    .collect(Collectors.groupingBy(p->p.getAddress().getCity()));
```

```
// Count of persons by state. Output: {IA=2, CA=1}
```

```
Map<String, Long> countByState = persons.stream()
    .collect(Collectors.groupingBy(p->p.getAddress().getState(),
        Collectors.counting()));
```

```
// Average age of persons by state. {IA=30.0, CA=20.0}
```

```
Map<String, Double> avegareAgeByState = persons.stream()
    .collect(Collectors.groupingBy((p)->p.getAddress().getState(),
        Collectors.averagingInt(Person::getAge)));
```

# Main Point 5

To obtain some information about a collection, we can lift the collection to a Stream, perform transformations at the Stream level, and then, by way of some terminal operation, collapse the Stream to obtain a final output. It is by virtue of accessing the powerful dynamics available in Stream that the result is obtained.

In a similar way, experience of transcending makes it possible to fulfill desires and intentions with a minimum of effort: When the mind transcends, awareness become saturated with the level from which all the laws of nature begin to operate – the unified field. Having the support of this powerful level, desires can effortlessly meet with fulfillment.

# Outline

1. Introduction to Java 8 Streams
2. Streams: Basic Facts and a 3-Step Template
3. Different Ways to Create Streams
4. Intermediate Operations on Streams
5. Stateful Intermediate Operations
6. Terminal Operations
7. Working with the Optional class
8. Reduce
9. Collecting Results
10. **Primitive Type Streams**
11. Stream Reuse and Lambda Libraries

# Primitive Type Streams

There are variations of Stream specifically designed for primitives: int, double, and long:

- IntStream
- DoubleStream
- LongStream

For primitive types short, char, byte, and boolean, use IntStream; for floats, use DoubleStream.

1. Creation methods are similar to those for Stream:

- a. IntStream ints = IntStream.of(1, 2, 4, 8);
- b. IntStream ones = IntStream.generate(() -> 1);
- c. IntStream naturalNums = IntStream.iterate(1, n -> n+1);

2. IntStream (and also LongStream) have static methods range and rangeClosed that generate integer ranges with step size one:

// Upper bound is excluded

```
IntStream zeroToNinetyNine = IntStream.range(0, 100);
```

// Upper bound is included

```
IntStream zeroToHundred = IntStream.rangeClosed(0, 100);
```

3. To convert a primitive type stream to an stream of objects, use the boxed() method:

```
Stream<Integer> integers = IntStream.range(0, 100).boxed();
```

4. To convert an object stream to a primitive type stream, there are methods `mapToInt`, `mapToLong`, and `mapToDouble`. In the examples, a Stream of strings is converted to an IntStream (of lengths).

```
Stream<String> words = ...;  
IntStream lengths = words.mapToInt(String::length);
```

5. The methods on primitive type streams are analogous to those on object streams. Here are the main differences:

- The `toArray` methods return primitive type arrays.
- Methods that yield an `Optional` result return an `OptionalInt`, `OptionalLong`, or `OptionalDouble`. These classes are analogous to the `Optional` class, but they have methods `getAsInt`, `getAsLong`, and `getAsDouble` instead of the `get` method.
- There are methods `sum`, `average`, `max`, and `min` that return the sum, average, maximum, and minimum. These methods are not defined for object streams. (Note that the functions `max` and `min` defined on an ordinary `Stream`, require a `Comparator` argument, and return an `Optional`.)

# Outline

1. Introduction to Java 8 Streams
2. Streams: Basic Facts and a 3-Step Template
3. Different Ways to Create Streams
4. Intermediate Operations on Streams
5. Stateful Intermediate Operations
6. Terminal Operations
7. Working with the Optional class
8. Reduce
9. Collecting Results
10. Primitive Type Streams
11. **Stream Reuse and Lambda Libraries**

# Can Streams Be Re-Used?

- Once a terminal operation has been called on a stream, the stream becomes unusable, and if you do try to use it, you will get an `IllegalStateException`.
- But sometimes it would make sense to have a Stream ready to be used for multiple purposes.
- Example** We have a `Stream<String>` that we might want to use for different purposes:

```
Folks.friends.stream().filter(name -> name.startsWith("N"))
```

Typical Uses:

- count the number of names obtained
- output the names in upper case to a List

But once the stream has been used once, we can't use it again.

# Stream Re-use Techniques

- Solution #1 One solution is to place the stream-creation code in a method and call it for different purposes. See Good solution in package `lesson9.lecture.streamreuse`
- Solution #2 Another solution is to capture all the free variables in the first approach as parameters of some kind of a Function (might be a BiFunction, TriFunction, etc, depending on the number of parameters). See Reuse solution in package `lesson9.lecture.streamreuse`
- The second solution leads to a useful way of storing stream pipelines for reuse similar to techniques from database management

# Creating a Lambda Library

Java 8 lets you perform *queries* to work with data in a Collection of some kind. The query style is similar to SQL queries.

Database Problem. You have a database table named Customer. Return a collection of the names of those Customers whose city of residence begins with the string “Ma”, arranged in sorted order.

Solution: `SELECT name FROM Customer WHERE city LIKE 'Ma%' ORDER BY name`

**Similar Java Problem:** You have a List of Customers. Output to a list, in sorted order, the names of those Customers whose city of residence begins with the string “Ma.”

### **Solution:**

```
List<String> listStr =  
    list.stream()  
        .filter(cust -> cust.getCity().startsWith("Ma"))  
        .map(cust -> cust.getName())  
        .sorted().collect(Collectors.toList());
```

# Turning Your Stream Pipeline into a Library Element

How to turn your solution into a reusable Lambda Library element:

*Identify the parameters and treat them as arguments for some kind of Java function-type interface (Function, BiFunction, TriFunction, etc).*

## Parameters in this problem:

- An input list of type `List<Customer>`
- A target string used to compare with name of city, of type `String`
- Return type: a list of strings: `List<String>`

# Turning Your Stream Pipeline into a Library Element (cont.)

These suggest using a BiFunction as follows:

```
public static final BiFunction<List<Customer>, String,  
List<String>> NAMES_IN_CITY = (list, searchStr) ->  
    list.stream()  
        .filter(cust -> cust.getCity()  
        .startsWith(searchStr))  
        .map(cust -> cust.getName())  
        .sorted()  
        .collect(Collectors.toList());
```

The Java solution can now be rewritten like this:

```
List<String> listStr =  
    LambdaLibrary.NAMES_IN_CITY.apply(list, "Ma");
```

See the code in lesson9.lecture.lambdalibrary.

# Connecting the Parts of Knowledge With the Wholeness of Knowledge

## *Lambda Libraries*

1. Prior to the release of Java 8, extracting or manipulating data in one or more lists or other Collection classes involved multiple loops and code that is often difficult to understand.
  2. With the introduction of lambdas and streams, Java 8 makes it possible to create compact, readable, reusable expressions that accomplish list-processing tasks in a very efficient way. These can be accumulated in a Lambda Library.
- 
3. *Transcendental Consciousness* is the field that underlies all thinking and creativity, and, ultimately, all manifest existence.
  4. *Impulses Within the Transcendental Field*. The hidden self-referral dynamics within the field of pure intelligence provides the blueprint for emergence of all diversity. This blueprint is formed from compact expressions of intelligence are coherently arranged in the first sprouting of existence.
  5. *Wholeness Moving Within Itself*. In Unity Consciousness, the fundamental forms out of which manifest existence is structured are seen to be vibratory modes of one's own consciousness.