MAHARISHI UNIVERSITY of MANAGEMENT

Engaging the Managing Intelligence of Nature

Computer Science Department

CS401 Modern Programming Practices (MPP)

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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 aggregrate 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 only 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. *<u>What They Are.</u>* 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 on 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

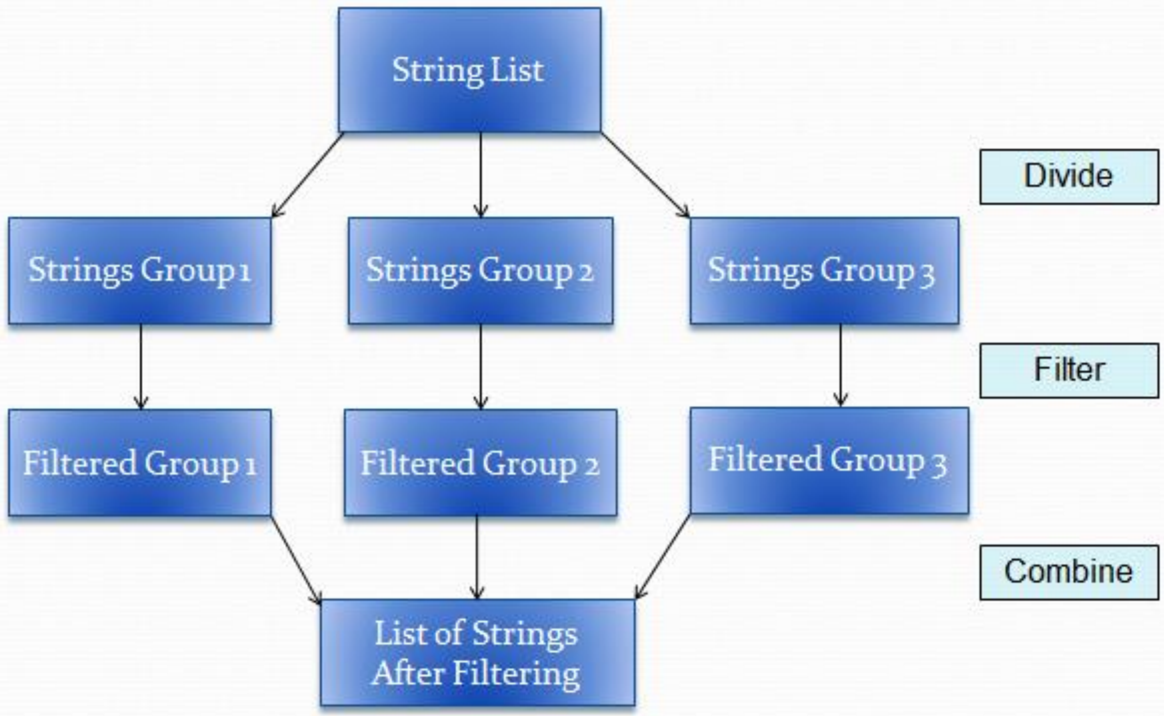
ii. Makes no commitment to an iteration path, so more parallelizable

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();
```



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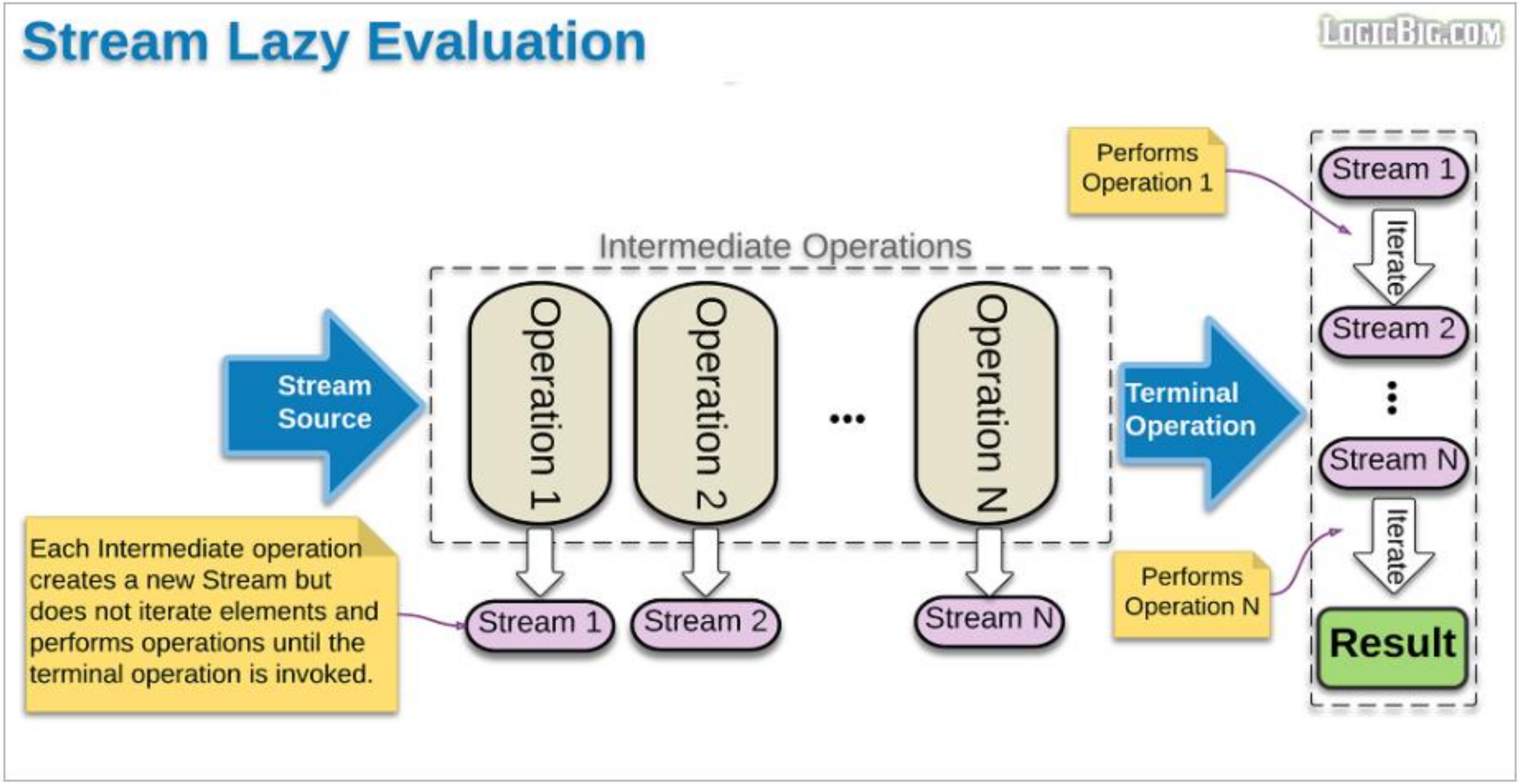
Facts About Streams

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.* So they are not executed until their result is needed. Example: In previous example, if you request only the first 5 words of length > 12, the filter method will stop filtering after the fifth match. This makes it possible to have (potentially) *infinite streams.*



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
```

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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 <u>zero</u> parameters.

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

   <u>Example</u>: `Stream` of constant values ("Echo"):

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

   <u>Example</u>: `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);
}
```

<u>Example:</u> `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 `Stream`s 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.

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.

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 `Character`s:

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

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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 Substream

- `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 References

1. *Class::new* is a fourth type of method reference, where the method is the *new* operator.

   <u>Examples:</u>

   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)

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);
}
```

See Demo: lesson9.lecture.constructorref.IntArrayExample

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.

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))
```

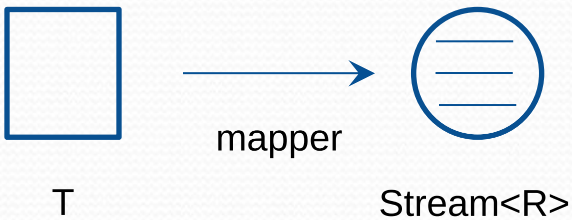
Output:

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

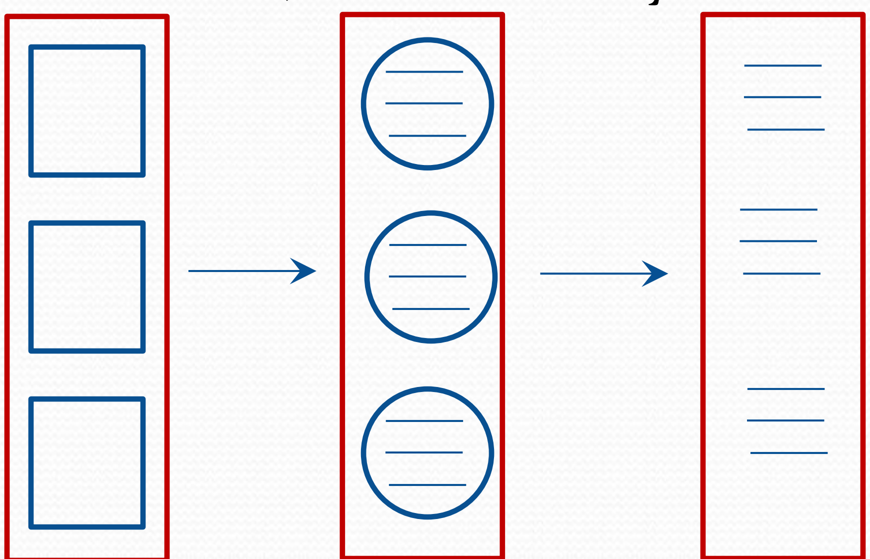
flatMap

Demo: lesson9.lecture.flatmapstream

- Start with `mapper: T → Stream<R>` (like `String → Stream<Character>`)



- `flatMap` transforms a `Stream` of T's first to a `Stream` of `Stream<R>'s`, and then finally to a `Stream` of `R's`



`flatMap(mapper)`

$$\begin{tikzcd} \mathrm{Stream}\langle T\rangle \arrow[r, "\mathrm{map(mapper)}"] \arrow[dr, "\mathrm{flatMap(mapper)}"'] & \mathrm{Stream}\langle \mathrm{Stream}\langle R\rangle\rangle \arrow[d, "\mathrm{flatMap(id)}"] \\ & \mathrm{Stream}\langle R\rangle \end{tikzcd}$$

flatMap(mapper) ==
map(mapper).flatMap((Stream s)-> s)

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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.

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: `y.length() - x.length()` is negative (so x < y) if x is longer than y

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 `Employee`s 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`

```
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 so can be chained; it modifies current `Comparator` by introducing its `compare` method just when the current `compare` method returns 0.
- we can get rid of the if/else branching using a `HashMap` – see Lab 9, Problem 5.

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;
    }
}
```

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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 `true` if any match is found, `false` otherwise; this one works well with parallel `streams`:

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

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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, give 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");
    }
}
```

```java
//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`.
- **<u>Example</u>**. 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 the `orElse` clause needs to obtain a value from a method call, use `orElseGet` instead.

- **<u>Example</u>**. Use the `orElseGet` version as an alternative to the following pattern (sometimes found when a `Connection` object is needed, when using JDBC)

"If X is null, initialize X, then return X."

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

Difference Between orElse and orElseGet

- If `orElse` is used when a method call is needed, even if `ofNullable` encounters a non-null input, the method call in `orElse` will still execute, but the return value is ignored.

In the code on previous slide, if we write instead

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

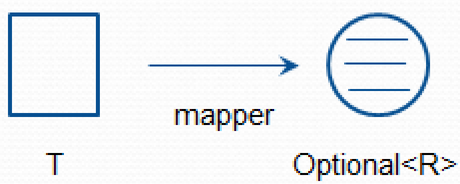
then, when `conn` is not null, `orElse` will cause `myGetConn()` to be invoked, but will ignore its return value and return `conn` instead.

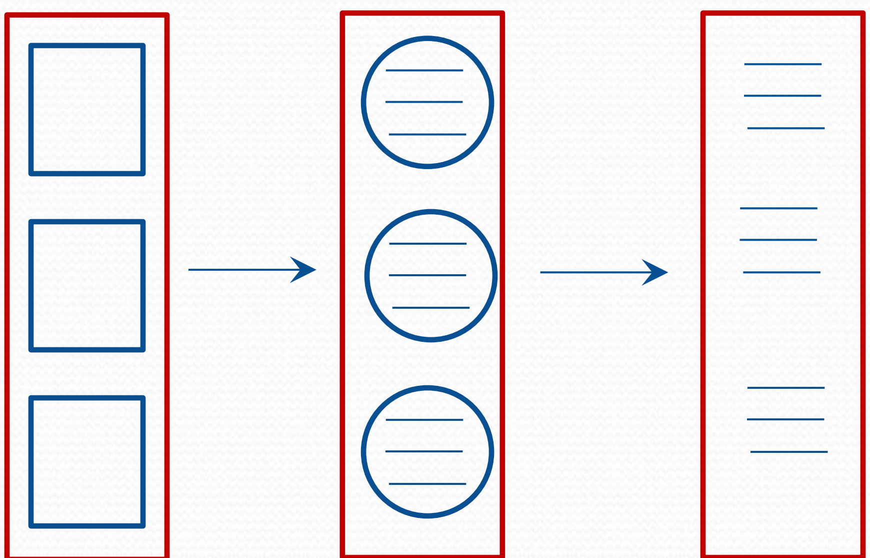
In the same scenario, the following code will *not* cause myGetConn to be invoked.

```
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>`





$$
\begin{tikzcd}
\mathrm{Optional}\langle T\rangle \arrow[r, "\mathrm{map(mapper)}"] \arrow[dr, "\mathrm{flatMap(mapper)}"'] & \mathrm{Optional}\langle \mathrm{Optional}\langle R\rangle\rangle \arrow[d, "\mathrm{flatMap(id)}"] \\
 & \mathrm{Optional}\langle R\rangle
\end{tikzcd}
$$

`flatMap(mapper)`

Example of Optional's flatMap

Consider ordinary 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 `flatMap` completely eliminates these (unnecessary) null checks

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

- **Note.** To get this nice behavior, you have to set up your classes so that they are using `Optional`. See Demo code

  lesson9.lecture.optional_flatmap.usingoptionals.optionalway

Monads in Java 8

- A *monad* is a special data structure, available in some languages, that serves as a wrapper class, to support various operations. In Java, these operations include filter and map. Monads are designed to support chaining operations, so that the output of each monad operation is another monad.
- Monads are considered to be a key construct in functional languages
- More formal definition: *Monads are chainable container types that trap values or computations and allow them to be transformed in confinement.*
- In Java 8, two monads were introduced:
  - `Optional`
  - `Stream`

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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 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 (`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:

```
sum1 = (0 + 2) + 3        sum2 = (0 + 4) + 1
combined = sum1 + sum2 = 10
```

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 product of an empty set of numbers?” By convention, the product is 1. (**Note** that 1 is the identity element for multiplication.)

  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) - 3)    //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:

```
diff1 = (0 - 2) - 3  diff2 = (0 - 1) - 4
combined = diff1 - diff2 = 0
```

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

Use reduce only on associative operations.

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

See the demo lesson9.lecture.reduce.

The reduce Operation (cont.)

- <u>The reduce method has an overloaded version with only one argument</u>.

- 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 2

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.

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Collecting Results

- One kind of terminal operation in a stream pipeline is a *reduction* that outputs a single value, like `max` or `count`. 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.

<u>Example</u>: Collecting into an `array`

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

<u>Example</u>: Collecting into a `List`

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

<u>Example</u>: Collecting into a `Set`

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

<u>Example</u>: 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.)

<u>Example</u> Collecting into a `map` – two typical examples.

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

//key = id, value = name

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

//key = id, value = the person object

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

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

```
(Person p) -> 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` must therefore be converted to (primitive) `ints` in order for summarizingInt to perform its tasks.

- The `summarizingInt` method expects an argument that is an implementation of the `ToIntFunction<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));
        }
    };
}
```

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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`.)

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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.
- **<u>Example</u>** We have a `Stream<String>` that we might want to use for different purposes:

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

Typical Uses:

1. count the number of names obtained
2. 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

- <u>Solution #1</u> 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

- <u>Solution #2</u> 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.

<u>Database Problem</u>. 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.

<u>Solution:</u> `SELECT name FROM Customer WHERE city LIKE 'Ma%' ORDER BY name`

<u>Similar Java Problem</u>: 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."

<u>Solution:</u>

```
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 coherently arranged.
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.