Lecture 10

Working with Streams

SOEN 6441, Summer 2018

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Outline

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From external iteration to internal iteration

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Collections API: External Iteration

```
List<Dish> vegetarianDishes = new ArrayList<>();
for(Dish d: menu){
  if(d.isVegetarian()){
    vegetarianDishes.add(d);
  }
}
```

Streams API: Internal Iteration

```
List<Dish> vegetarianDishes = menu.stream()
                                  .filter(Dish::isVegetarian)
                                  .collect(toList());
```

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Filtering with a predicate

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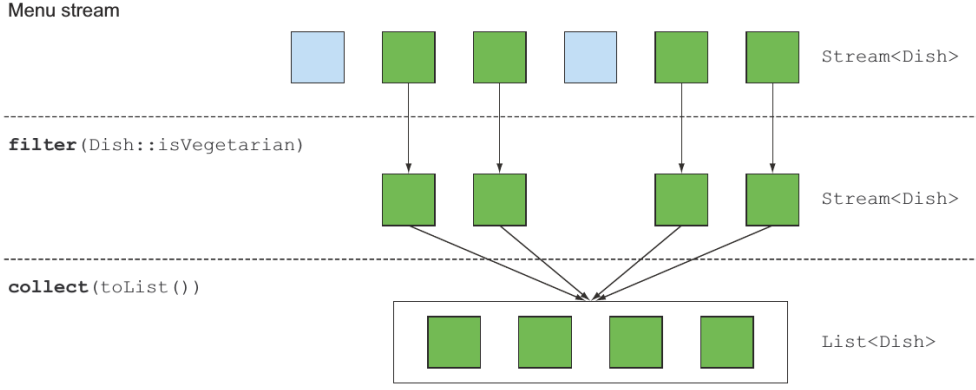
Get all vegetarian friendly dishes

```
List<Dish> vegetarianDishes = menu.stream()
                                  .filter(Dish::isVegetarian)
                                  .collect(toList());
```



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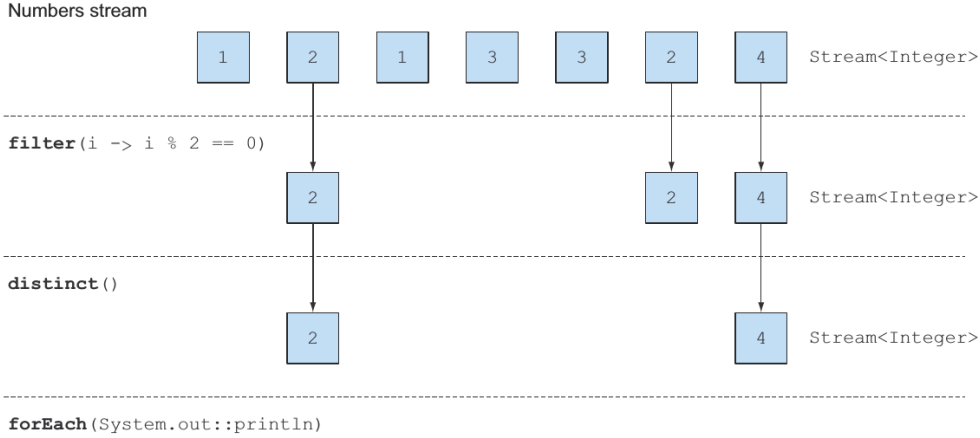
Filtering unique elements

```
List<Integer> numbers = Arrays.asList(1, 2, 1, 3, 3, 2, 4);
numbers.stream()
       .filter(i -> i % 2 == 0)
       .distinct()
       .forEach(System.out::println);
```



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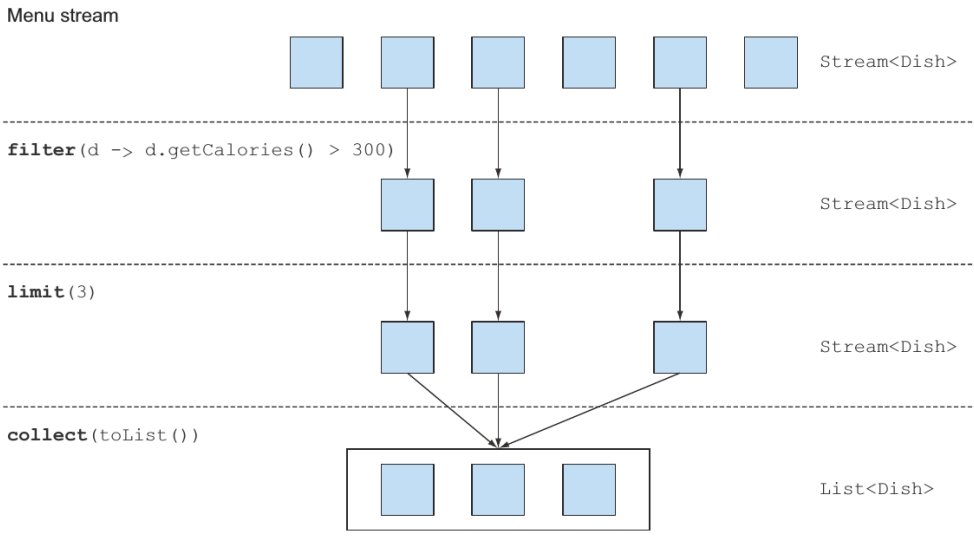
Truncating a stream

```
List<Dish> dishes = menu.stream()
                        .filter(d -> d.getCalories() > 300)
                        .limit(3)
                        .collect(toList());
```



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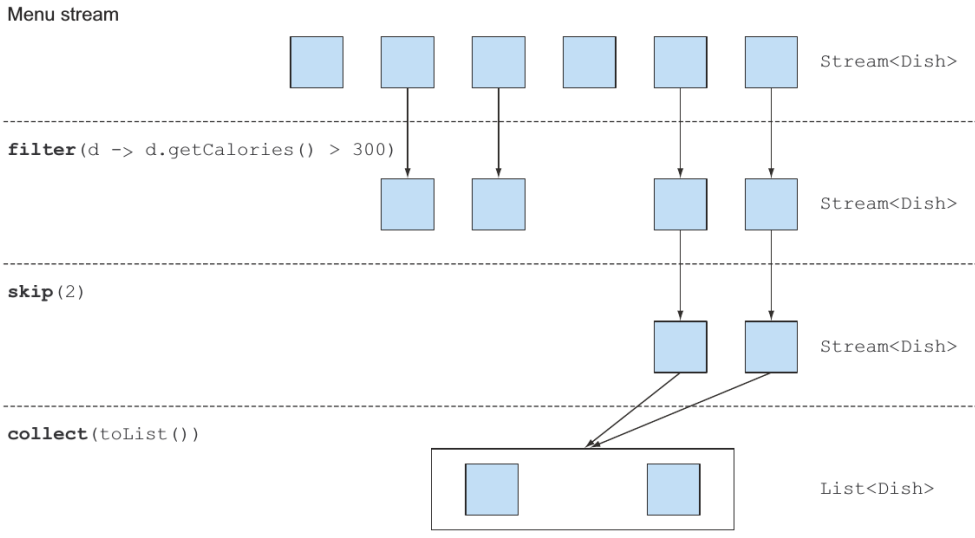
Skipping elements

```
List<Dish> dishes = menu.stream()
                        .filter(d -> d.getCalories() > 300)
                        .skip(2)
                        .collect(toList());
```



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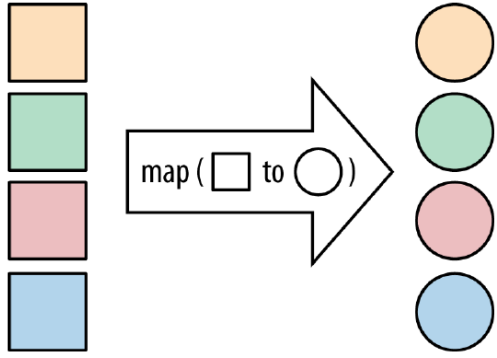
Map: Applying a function to each element of a stream

```
List<String> dishNames = menu.stream()
                             .map(Dish::getName)
                             .collect(toList());
```



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Map Examples

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Return the length of each string in a list

```
List<String> words = Arrays.asList("Java8","Lambdas","In","Action");
List<Integer> wordLengths = words.stream()
                                 .map(String::length)
                                 .collect(toList());
```

Return the length of each name of a dish

```
List<Integer> dishNameLengths = menu.stream()
                                    .map(Dish::getName)
                                    .map(String::length)
                                    .collect(toList());
```

Flattening streams

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Obtain unique characters for a list of words?

Input: `["Hello", "World"]`

Output: `["H", "e", "l", "o", "W", "r", "d"]`

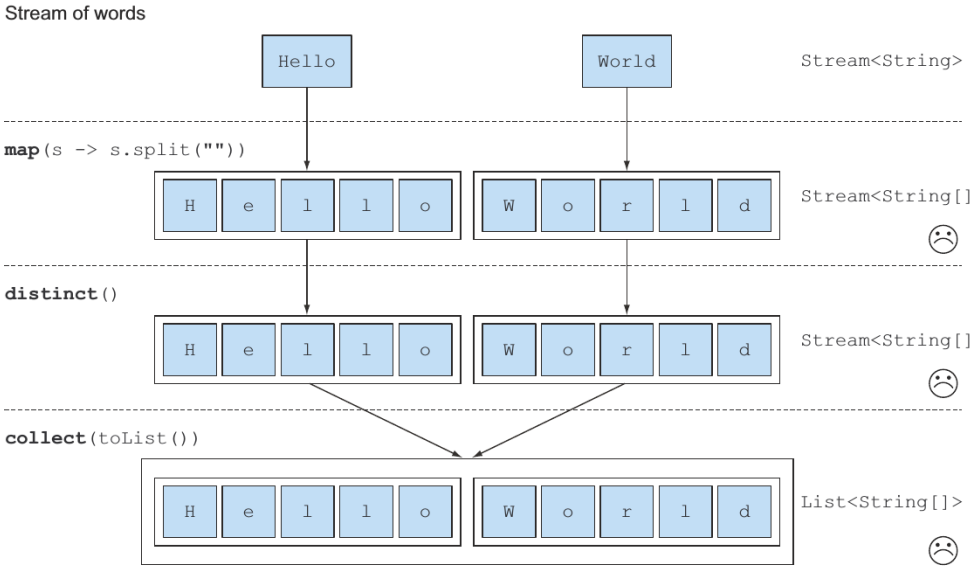
First attempt

```
words.stream()
     .map(word -> word.split(""))
     .distinct()
     .collect(toList());
```

Mapping from `String` to `String[]`

- here, `map` returns a string array `String[]` for *each* word
- so, the result from `map` is a `Stream<String[]>`
- but what we need is a single string array

Incorrect use of `map`



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Using `flatMap`

```
List<String> uniqueCharacters = words.stream()
                                     .map(w -> w.split(""))
                                     .flatMap(Arrays::stream)
                                     .distinct()
                                     .collect(Collectors.toList());
```

`flatMap`

- replace a value with a `Stream`
- and concatenate all the streams together

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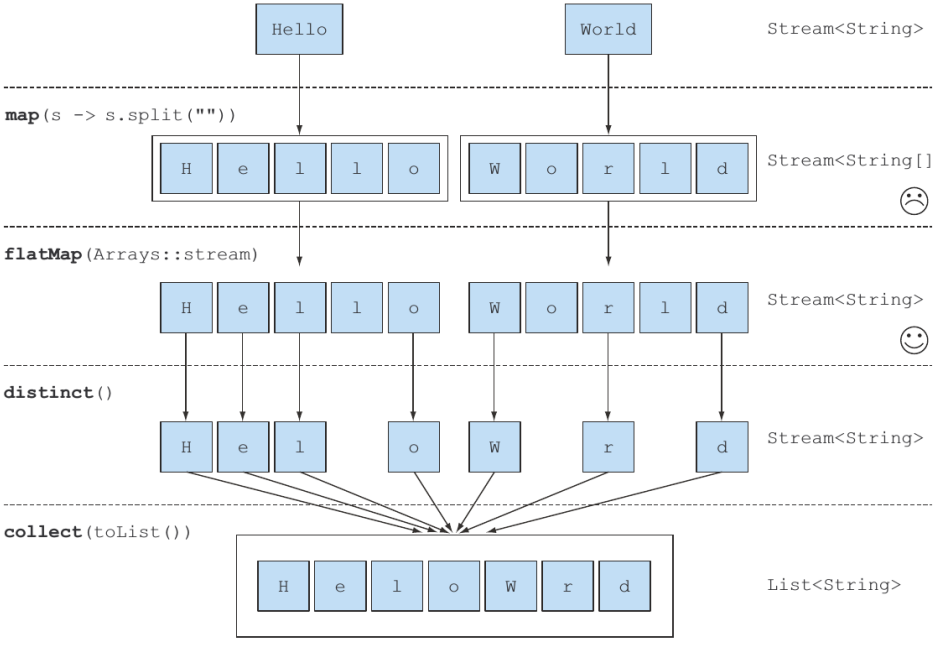
Stream of words



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Checking to see if a predicate matches at least one element

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Is there at least one vegetarian dish on the menu?

```
if(menu.stream().anyMatch(Dish::isVegetarian)){
  System.out.println("The menu is (somewhat) vegetarian friendly!!");
}
```

`anyMatch`

- returns a `boolean`
- terminal operation

Checking to see if a predicate matches all elements

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Is the menu healthy (all dishes < 1000 calories)?

```
boolean isHealthy = menu.stream()
                        .allMatch(d -> d.getCalories() < 1000);
```

`allMatch`

- returns a `boolean`
- terminal operation

Checking to see if a predicate matches no elements

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Is the menu healthy (all dishes < 1000 calories)?

```
boolean isHealthy = menu.stream()
                        .noneMatch(d -> d.getCalories() >= 1000);
```

`noneMatch`

- returns a `boolean`
- terminal operation

Short-circuiting

The operations `anyMatch`, `allMatch`, and `noneMatch` are short-circuiting.

Short-circuiting evaluation

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Evaluating Boolean expressions

Evaluating `(A && B)`

- Check if `A` is `false`.
- If yes, return `false`; otherwise,
- evaluate `B` and return its result.

Similarly, evaluate `(A || B)` as

- Check if `A` is `true`.
- If yes, return `true`; otherwise,
- evaluate `B` and return its result.

This is know as short circuit (or lazy) evaluation.

Non-short circuit operators

The operators `&` and `|`, when applied to `boolean` operands, are non-short circuit (usually applied on `integer` for bitwise and/or operations).

Finding an element

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Find any dish that's vegetarian

```
Optional<Dish> dish = menu.stream()
                          .filter(Dish::isVegetarian)
                          .findAny();
```

`Optional<T>`

What if there is no vegetarian dish?

- Java 7: return `null`
- Java 8: return `Optional<T>`

Working with `Optional` safer than `null` value checking

Java 8 `Optional<T>`

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`java.util.Optional`

`isPresent()` returns `true` if `Optional` contains a value, false otherwise

`ifPresent(Consumer<T> block)` executes the given block if a value is present

`T get()` returns the value if present; otherwise it throws a `NoSuchElement` Exception.

`T orElse(T other)` returns the value if present; otherwise it returns a default value.

Example

```
menu.stream()
    .filter(Dish::isVegetarian)
    .findAny()
    .ifPresent(d -> System.out.println(d.getName());
```

Finding the first element

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Find the first square of a number that's divisible by 3

```
List<Integer> someNumbers = Arrays.asList(1, 2, 3, 4, 5);
Optional<Integer> firstSquareDivisibleByThree =
    someNumbers.stream()
               .map(x -> x * x)
               .filter(x -> x % 3 == 0)
               .findFirst();
```

`findFirst` vs. `findAny`

Difference is in parallelism:

- `findAny` can process a stream in parallel
- `findFirst` cannot

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Summing the elements in a stream

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Java 7 Style

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

Summing elements

We are reducing a list of numbers to a single number (here: the sum)

- works iteratively
- two parameters: initial value for `sum` (here `0`) and the operator(here `+`)

Summing elements using `reduce`

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Java 8 Style

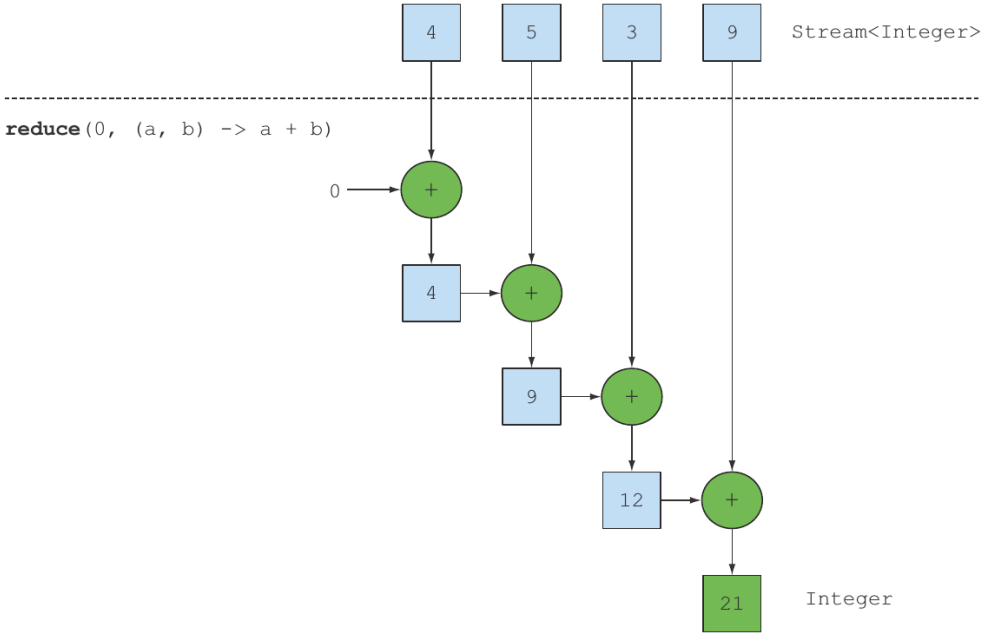
```
int sum = numbers.stream().reduce(0, (a, b) -> a + b);
```

`reduce`

two arguments:

- an initial value (here `0`)
- a `BinaryOperator<T>` to combine two elements and produce a new value here the lambda `(a, b) -> a + b`

Numbers stream



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More `reduce` Examples

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Multiply instead of add

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

No initial value (overloaded `reduce`)

```
Optional<Integer> sum = numbers.stream().reduce((a, b) -> (a + b));
```

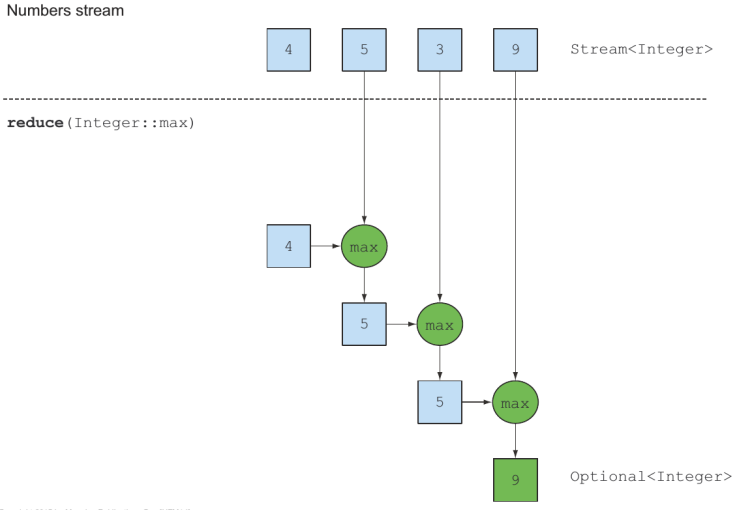
Compute sum in parallel

```
int sum = numbers.parallelStream().reduce(0, Integer::sum);
```

Maximum and Minimum

Compute minimum and maximum in a stream using `reduce`

```
Optional<Integer> min = numbers.stream().reduce(Integer::min);
Optional<Integer> max = numbers.stream().reduce(Integer::max);
```



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Stream Operations: Stateful vs. stateless

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Stateless Operations

- Take each input element and return zero or one result
- E.g., `map` or `filter`
- Do not need internal state (unless added in lambda)

Stateful Operations

- Operations need to keep internal state to accumulate result
- E.g., `reduce`, `sum`, or `max`
- Internal state is of bounded size (independent of stream size)

Unbounded Stateful Operations

- Operations requiring all elements in the stream to be buffered
- E.g., `sorted` or `distinct`
- Internal state is of unbounded size
- Problematic for large (or infinite) input streams

Stream Operations Summary (I)

Operation	Type	Return type	Type/functional interface used	Function descriptor
`filter`	Intermediate	`Stream<T>`	`Predicate<T>`	`T -> boolean`
`distinct`	Intermediate (stateful-unbounded)	`Stream<T>`		
`skip`	Intermediate (stateful-bounded)	`Stream<T>`	`long`	
`limit`	Intermediate (stateful-bounded)	`Stream<T>`	`long`	
`map`	Intermediate	`Stream<R>`	`Function<T, R>`	`T -> R`
`flatMap`	Intermediate	`Stream<R>`	`Function<T, Stream<R>>`	`T -> Stream<R>`
`sorted`	Intermediate (stateful-unbounded)	`Stream<T>`	`Comparator<T>`	`(T, T) -> int`

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Stream Operations Summary (II)

Operation	Type	Return type	Type/functional interface used	Function descriptor
anyMatch	Terminal	boolean	Predicate<T>	T -> boolean
noneMatch	Terminal	boolean	Predicate<T>	T -> boolean
allMatch	Terminal	boolean	Predicate<T>	T -> boolean
findAny	Terminal	Optional<T>		
findFirst	Terminal	Optional<T>		
forEach	Terminal	void	Consumer<T>	T -> void
collect	terminal	R	Collector<T, A, R>	
reduce	Terminal (stateful-bounded)	Optional<T>	BinaryOperator<T>	(T, T) -> T
count	Terminal	long		

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Example: Traders executing transactions

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Your job is to write programs that can answer:

1. Find all transactions in the year 2011 and sort them by value (small to high).
2. What are all the unique cities where the traders work?
3. Find all traders from Cambridge and sort them by name.
4. Return a string of all traders' names sorted alphabetically.
5. Are any traders based in Milan?
6. Print all transactions' values from the traders living in Cambridge.
7. What's the highest value of all the transactions?
8. Find the transaction with the smallest value.

`Trader` class

```
public class Trader{
  private final String name;
  private final String city;

  public Trader(String n, String c){
    this.name = n;
    this.city = c;
  }

  public String getName(){
    return this.name;
  }

  public String getCity(){
    return this.city;
  }

  public String toString(){
    return "Trader:"+this.name + "␣in␣" + this.city;
  }
}
```

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`Transaction` class

```
public class Transaction{
  private final Trader trader;
  private final int year;
  private final int value;

  public Transaction(Trader trader, int year, int value){
    this.trader = trader;
    this.year = year;
    this.value = value;
  }

  public Trader getTrader(){ return this.trader; }
  public int getYear(){ return this.year; }
  public int getValue(){ return this.value; }

  public String toString(){
    return "{" + this.trader + ", " +
      "year: "+this.year+", " +
      "value:" + this.value +"}";
  }
```

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Traders and Transactions Data

```
Trader raoul = new Trader("Raoul", "Cambridge");
Trader mario = new Trader("Mario","Milan");
Trader alan = new Trader("Alan","Cambridge");
Trader brian = new Trader("Brian","Cambridge");

List<Transaction> transactions = Arrays.asList(
  new Transaction(brian, 2011, 300),
  new Transaction(raoul, 2012, 1000),
  new Transaction(raoul, 2011, 400),
  new Transaction(mario, 2012, 710),
  new Transaction(mario, 2012, 700),
  new Transaction(alan, 2012, 950)
)
```

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Find all transactions in 2011 and sort by value (small to high)

Solution

```
List<Transaction> tr2011 =
    transactions.stream()
                .filter(transaction -> transaction.getYear() == 2011)
                .sorted(comparing(Transaction::getValue))
                .collect(toList());
```

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What are all the unique cities where the traders work?

Solution

```
List<String> cities =
    transactions.stream()
                .map(transaction -> transaction.getTrader().getCity())
                .distinct()
                .collect(toList());
```

Alternative solution

```
Set<String> cities =
    transactions.stream()
                .map(transaction -> transaction.getTrader().getCity())
                .collect(toSet());
```

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Find all traders from Cambridge and sort them by name

Solution

```
List<Trader> traders =
    transactions.stream()
                .map(Transaction::getTrader)
                .filter(trader -> trader.getCity().equals("Cambridge"))
                .distinct()
                .sorted(comparing(Trader::getName))
                .collect(toList());
```

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Return a string of all traders' names sorted alphabetically

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Solution

```
String traderStr =
    transactions.stream()
                .map(transaction -> transaction.getTrader().getName())
                .distinct()
                .sorted()
                .reduce("", (n1, n2) -> n1 + n2);
```

Alternative solution

```
String traderStr =
    transactions.stream()
                .map(transaction -> transaction.getTrader().getName())
                .distinct()
                .sorted()
                .collect(joining());
```

Are any traders based in Milan?

Solution

```
boolean milanBased =
    transactions.stream()
                .anyMatch(transaction -> transaction.getTrader()
                                                    .getCity()
                                                    .equals("Milan"));
```

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Print all transactions' values from the traders living in Cambridge

Solution

```
transactions.stream()
            .filter(t -> "Cambridge".equals(t.getTrader().getCity()))
            .map(Transaction::getValue)
            .forEach(System.out::println);
```

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What's the highest value of all the transactions?

Solution

```
Optional<Integer> highestValue =
    transactions.stream()
                .map(Transaction::getValue)
                .reduce(Integer::max);
```

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Find the transaction with the smallest value

Solution

```
Optional<Transaction> smallestTransaction =
    transactions.stream()
                .reduce((t1, t2)
                        -> t1.getValue() < t2.getValue() ? t1 : t2);
```

Alternative solution

```
Optional<Transaction> smallestTransaction =
    transactions.stream()
                .min(comparing(Transaction::getValue));
```

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Numeric Streams

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Compute total number of calories in a menu

```
int calories = menu.stream()
                   .map(Dish::getCalories)
                   .reduce(0, Integer::sum);
```

Issues

- Each `Integer` needs to be unboxed (costly!)
- Cannot call `sum` directly, i.e.,

```
int calories = menu.stream()
                   .map(Dish::getCalories)
                   .sum();
```

  does not work.

Solution: primitive stream specializations.

Primitive stream specializations

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Mapping to a numeric stream

```
int calories = menu.stream()
                   .mapToInt(Dish::getCalories)
                   .sum();
```

mapToInt

- returns an `IntStream` (rather than `Stream<Integer>`)
- can call `sum` on `IntStream`
- other operations: `max`, `min`, `average`
- empty stream: result = 0

Converting back to a stream of objects

```
IntStream intStream = menu.stream().mapToInt(Dish::getCalories);

Stream<Integer> stream = intStream.boxed();
```

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Default Values: `OptionalInt`

Find maximal element in an `IntStream`

```
OptionalInt maxCalories = menu.stream()
                              .mapToInt(Dish::getCalories)
                              .max();
```

Process the `OptionalInt`

```
int max = maxCalories.orElse(1);
```

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Numeric ranges

```
IntStream evenNumbers = IntStream.rangeClosed(1, 100)
                                 .filter(n -> n % 2 == 0);

System.out.println(evenNumbers.count());
```

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Streams from Values

Example: Stream of strings

```
Stream<String> stream =
    Stream.of("Java␣8␣", "Lambdas␣", "In␣", "Action");
stream.map(String::toUpperCase).forEach(System.out::println);
```

Example: Empty stream

```
Stream<String> emptyStream = Stream.empty();
```

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Streams from arrays

Example: Stream of primitive `ints`

```
int[] numbers = {2, 3, 5, 7, 11, 13};
int sum = Arrays.stream(numbers).sum();
```

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Streams from files

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Example: Count lines in a file

```
long lineCount = Files.lines(Paths.get("data.text")).count();
```

Example: Count unique words in a file

```
long uniqueWords = 0;
try(Stream<String> lines =
      Files.lines(Paths.get("data.txt"), Charset.defaultCharset())){
  uniqueWords = lines.flatMap(line -> Arrays.stream(line.split("␣")))
                     .distinct()
                     .count();
} catch(IOException e){
 // Deal with the exception
}
```

Streams from functions: creating infinite streams!

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Example

```
Stream.iterate(0, n -> n + 2)
      .limit(10)
      .forEach(System.out::println);
```

`iterate`

- takes initial value and a lambda (`UnaryOperator<T>`)
- infinite stream: creates values on demand (unbounded)
- usually should be bounded through `limit(n)`
- computed sequentially: new result depends on previous

Generate

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Generate five random numbers in $[0, 1)$

```
Stream.generate(Math::random)
      .limit(5)
      .forEach(System.out::println);
```

`generate`

- takes a lambda of type `Supplier<T>`
- like `iterate`, and infinite stream: creates values on demand
- Supplier lambda should not have internal state for parallelization

How *not* to do it: Generating the Fibonacci Sequence

Fibonacci Sequence: 0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55...

First two numbers are 0, 1; each subsequent number is the sum of the previous two.

Writing a function for `generate`

```
IntSupplier fib = new IntSupplier(){
  private int previous = 0;
  private int current = 1;
  public int getAsInt(){
    int oldPrevious = this.previous;
    int nextValue = this.previous + this.current;
    this.previous = this.current;
    this.current = nextValue;
    return oldPrevious;
  }
};

IntStream.generate(fib).limit(10).forEach(System.out::println);
```

Mutable State

- The `fib` object has mutable state (the code has side effects)
- Cannot be used in parallel execution
- In general, prefer immutable approach (side effect-free code)

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Summary

Streams

- The Streams API lets you express complex data processing queries.
- You can filter and slice a stream using `filter`, `distinct`, `skip`, and `limit`
- You can extract or transform elements of a stream using `map` and `flatMap`
- You can find elements in a stream using the `findFirst` and `findAny` methods
- You can match a given predicate in a stream using `allMatch`, `noneMatch`, and `anyMatch`
- These methods make use of short-circuiting
- You can combine all elements of a stream using `reduce`
- Some operations such as `filter` and `map` are stateless; some operations such as `reduce` store state to calculate a value and are called stateful
- There are three primitive specializations of streams: `IntStream`, `DoubleStream`, and `LongStream`
- Streams can be created from a collection or from values, arrays, files, and specific methods such as `iterate` and `generate`
- An infinite stream is a stream that has no fixed size.

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Reading Material

Required

- [UFM14, Chapter 5] (Working with Streams)

Supplemental

- [War14, Chapter 3] (Streams)

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References

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