# Java Stream

## Object Oriented Programming

http://softeng.polito.it/courses/09CBI

Version 2.1.0

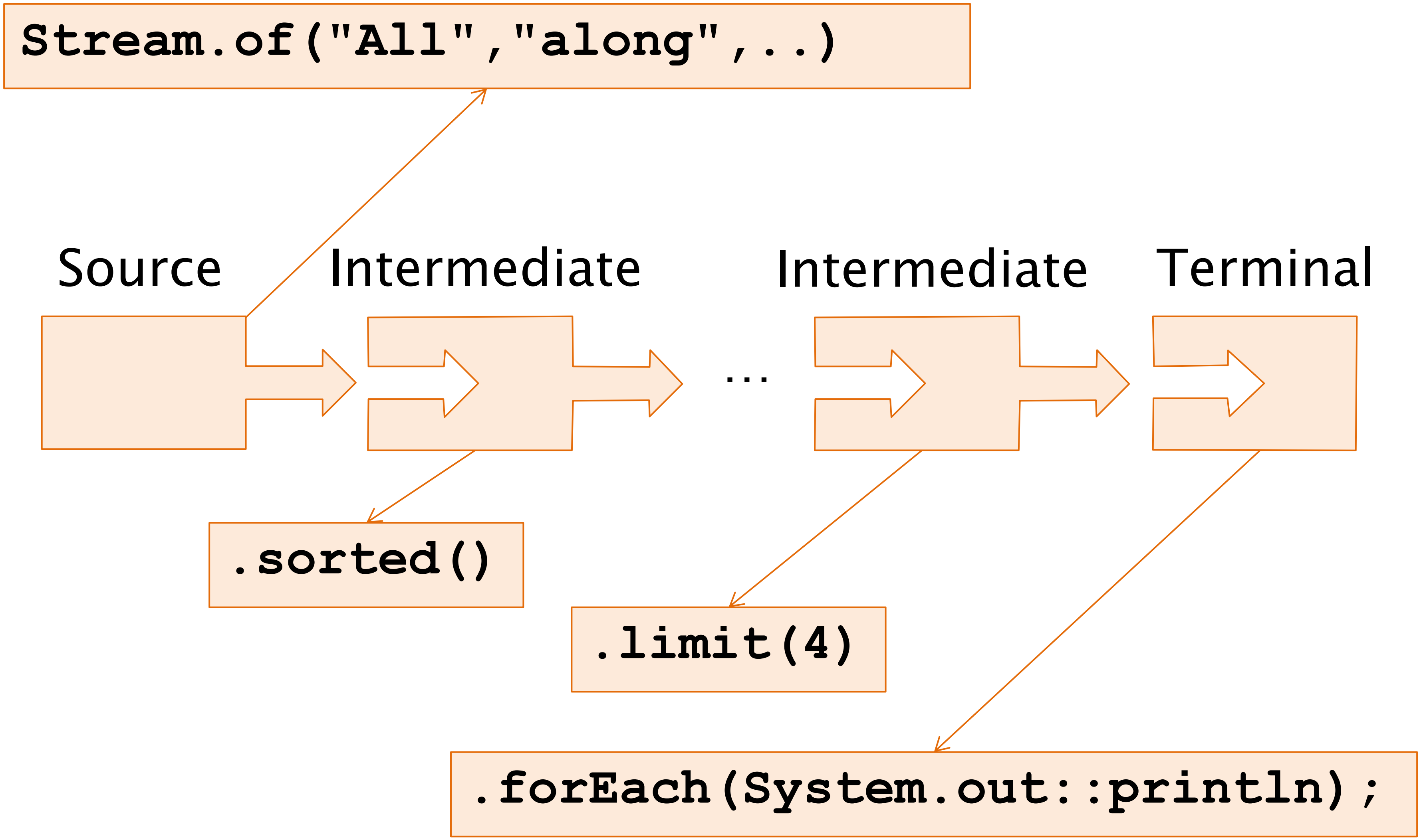
# Stream

A sequence of elements from a source that supports data processing operations.

- Operations are defined by means of behavioral parameterization

- Basic features:
  - Pipelining
  - Internal iteration:
    - no explicit loops statements
  - Lazy evaluation (*pull*):
    - no work until a terminal operation is invoked

# Pipelining



Stream.of("All","along",..)
Source
Intermediate
Intermediate
Terminal
...
.sorted()
.limit(4)
.forEach(System.out::println);

# Reminder:functional interfaces

- An interface with exactly one method
- The semantics is purely functional
  - The result of the method depends solely on the arguments
  - There are no side-effects on attributes
- Can be implemented as lambda expressions
- Predefined interfaces are defined in
  - **`java.util.function`**

# Standard Functional Interfaces

| Interface | Method |
|---|---|
| `Function <T,R>` | `R apply(T t)` |
| `BiFunction <T,U,R>` | `R apply(T t, U u)` |
| `BinaryOperator <T>` | `T apply(T t, T u)` |
| `UnaryOperator <T>` | `T apply(T t)` |
| `Predicate <T>` | `boolean test(T t)` |
| `Consumer <T>` | `void accept(T t)` |
| `BiConsumer <T,U>` | `void accept(T t, U u)` |
| `Supplier <T>` | `T get()` |

# Primitive specializations

- Functional interfaces handle references
- Specialized versions are defined for primitive types ( **`int`**, **`long`**, **`double`**, **`boolean`** )
- Functions: **`To`*`Type`*`Function`**
  **`Type1ToType2Function`**
- Suppliers: ***`Type`*`Supplier`**
- Predicate: ***`Type`*`Predicate`**
- Consumer: ***`Type`*`Consumer`**

# Source operations

| Operation | Args | Purpose |
| --- | --- | --- |
| `static Arrays.stream` | `T[]` | Returns a stream from an existing array |
| `default Collection.stream` | - | Returns a stream from a collection |
| `static Stream.of` | `T...` | Creates stream from the variable list of arguments/array |

# Stream source

- Arrays
  - `Stream<T> stream()`

```
String[] s={"Red", "Green", "Blue”}.
Arrays.stream(s)
            .forEach(System.out::println)
```

- Stream of
  - `static Stream<T> of(T... values)`

```
Stream.of("Red", "Green", "Blue”).
            forEach(System.out::println);
```

# Stream source

- Collection
  - `Stream<T> stream()`

```
Collection<Student> oopClass =
                    new LinkedList<>();
oopClass.add(
       new Student(100,"John","Smith"));
…
oopClass.stream().
         forEach(System.out::println);
```

# Source generation in **`Stream`**

| Operation | Args | Purpose |
|---|---|---|
| `generate()` | `Supplier<T> s` | Elements are generated by calling `get()` method of the supplier |
| `iterate()` | `T seed, UnaryOperator<T> f` | Starts with the seed and computes next element by applying operator to previous element |
| `empty()` | | Returns an empty stream |

# Stream source generation

- Generate elements using a **`Supplier`**

```
Stream.generate(
    () -> Math.random()*10 )
```

- Generate elements from a seed

```
Stream.iterate( 0,
    (prev) -> prev + 2 )
```

  - Warning: they generate infinite streams

# Numeric streams

- Provided for basic numeric types
  - `DoubleStream`
  - `IntStream`
  - `LongStream`
- Conversion methods from `Stream<T>`
  - `mapToX()`
- Generator method: `range(start,end)`
- New terminal operations e.g. `average()`
- More efficient: no boxing and unboxing

# Numeric streams

24 ns per element

```
IntStream seq = IntStream.generate(
                 ()-> (int)(Math.random()*100));
int max = seq.limit(10).max().getAsInt();
```

30 ns per element

```
Stream<Integer> seq = Stream.generate(
                 ()-> (int)(Math.random()*100));
int max = seq.limit(10)
             .max(naturalOrder()).get();
```

~ 6ns for boxing + unboxing

# Intermediate operations

| Return type | Operation | Arg. type | Ex. argument |
|---|---|---|---|
| `Stream<T>` | `filter` | `Predicate<T>` | `T -> boolean` |
| `Stream<T>` | `limit` | `int` | |
| `Stream<T>` | `skip` | filtering based on position<br>`int` | |
| `Stream<T>` | `sorted` | *optional* `Comparator<T>` | `(T, T) -> int` |
| `Stream<T>` | `distinct` | filtering duplicate elements<br>- | |
| `Stream<R>` | `map` | `Function<T, R>` | `T -> R` |

# Basic filtering

- `default Stream<T> distinct()`
  - Discards duplicates
- `default Stream<T> limit(int n)`
  - Retains only first $n$ elements
- `default Stream<T> skip(int n)`
  - Discards the first $n$ elements

# Filtering

- **`default Stream<T> filter(Predicate<T>)`**
  - Accepts as predicate
    - boolean method reference

```
oopClass.stream().
         filter(Student::isFemale).
         forEach(System.out::println);
```

    - lambda

```
oopClass.stream().
  filter(s->s.getFirst().equals("John")).
  forEach(System.out::println);
```

# Sorting

- **`default Stream<T> sorted()`**
  - Sorts the elements of the stream
  - Either in natural order

```
oopClass.stream().
        sorted().
        forEach(System.out::println);
```

  - or with comparator

```
oopClass.stream().
       sorted(comparingInt(Student::getId).
       forEach(System.out::println);
```

# Mapping

- **`default Stream<R> map(Function<T,R> mapper)`**
  - Transforms each element of the stream using the mapper function

```
oopClass.stream().
      map(Student::getFirst).
      forEach(System.out::println);
```

# Mapping to primitive streams

- Defined for the main primitive types:

```
IntStream mapToInt(ToIntFunction<T> mapper)
LongStream mapToLong(ToLongFunction<T> m)
DoubleStream mapToDouble(ToDoubleFunction<T>m)
```

  - Improve efficiency

```
oopClass.stream().
      map(Student::getFirst).
      mapToInt(String::length).
      forEach(System.out::println);
```

# Flat mapping

flat because it makes 3D types to 2D

- Context:
  - Stream elements are containers (e.g. List)
    - Or elements are mapped to containers
- Problem:
  - Processing should be applied to elements inside those containers
- Solution:
  - Use the **`flatMap()`** method

# Flat mapping

**`<R> Stream<R>`**

**`flatMap(Function<T, Stream<R>> mapper)`**

- Extracts a stream from each incoming stream element
- Concatenate together the resulting streams

- Typically
  - **`T`** is a **`Collection`** (or a derived type)
  - **`mapper`** can be **`Collection::stream`**

# Flat mapping

- `<R> Stream<R> flatMap( Function<T,Stream<R>> mapper)`

```
oopClass.stream().                          Stream<Student>
    map(Student::enrolledIn).
                                Stream<Collection<Course>>
    flatMap(Collection::stream).
    distinct().                                  Stream<Course>
    map(Course::getTitle).                       Stream<String>
    forEach(System.out::println);
```

# Terminal Operations

| Operation | Return | Purpose |
|---|---|---|
| `findAny()` | `Optional<T>` | Returns the first element (order **does not** count) |
| `findFirst()` | `Optional<T>` | Returns the first element (order counts) |
| `min()` / `max()` | `Optional<T>` | Finds the min/max element based on the comparator argument |
| `count()` | `long` | Returns the number of elements in the stream |
| `forEach()` | `void` | Applies the Consumer function to all elements in the stream |

# Terminal Operation – Predicate

| Operation | Return | Purpose |
|---|---|---|
| `anyMatch()` | `boolean` | Checks if any element in the stream matches the predicate |
| `allMatch()` | `boolean` | Checks if all the elements in the stream match the predicate |
| `noneMatch()` | `boolean` | Checks if none element in the stream match the predicate |

# Kinds of Operations

- Stateless operations
  - No internal storage is required
    - E.g. map, filter
- Stateful operations
  - Require internal storage, can be
    - Bounded: require a fixed amount of memory
      - E.g. reduce, limit
    - Unbounded: require unlimited memory
      - E.g. sorted, collect

# Terminal operations

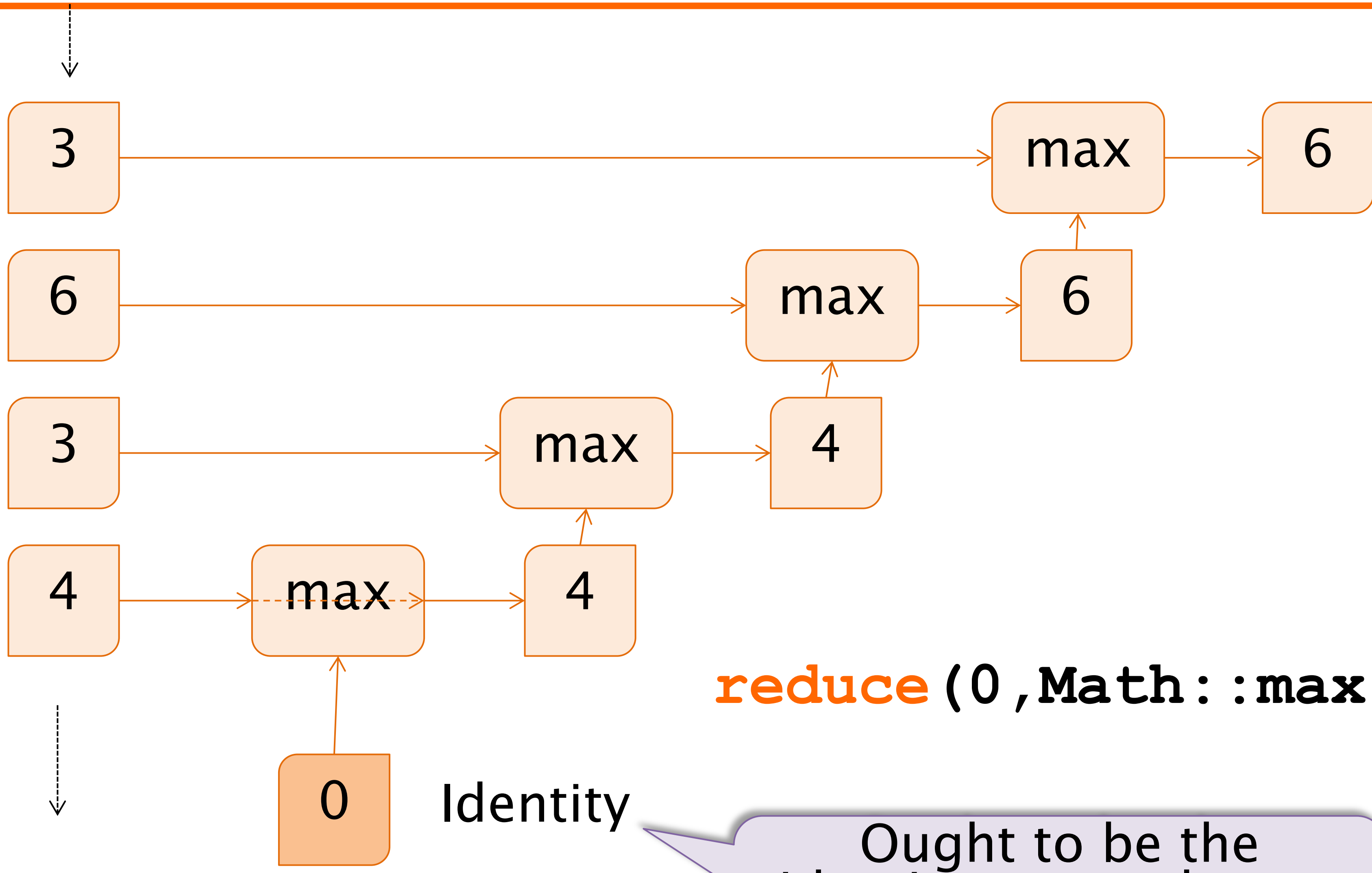
| Operation | Arguments | Purpose |
| --- | --- | --- |
| `reduce()` | `T, BinaryOperator<T>` | Reduces the elements using an identity value and an associative merge operator |
| `collect()` | `Collector<T,A,R>` | Reduces the stream to create a collection such as a List, a Map, or even an Integer. |

# Reducing

- **`T reduce(T identity, BinaryOperator<T> merge)`**
  - Reduces the elements of this stream, using the provided identity value and an associative merge function

```
int m=oopClass.stream().
        map(Student::getFirst).
        map(String::length).
        reduce(0,Math::max);
```

# Reducing




**reduce**(0,Math::max)

Ought to be the identity operand w.r.t. the merge operator

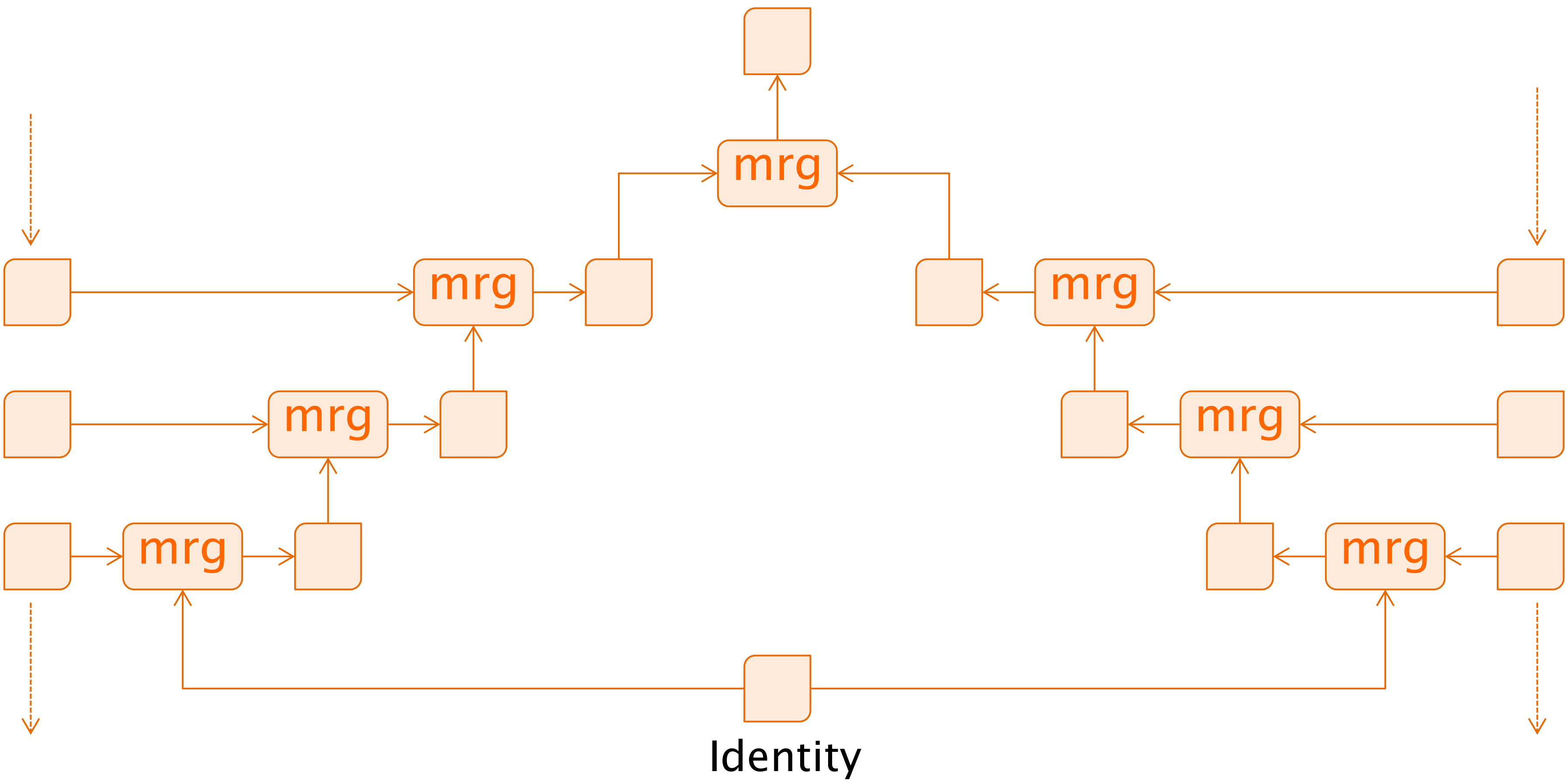
# Parallel streams

```
Stream.iterate(Integer.of(numbers)
      .reduce(0,Math::max);
```

```
Stream.iterate(Integer.of(numbers)
      .parallel()
      .reduce(0,Math::max);
```

Up to $n$ times faster
($n$ = number of CPU cores)

# Parallelized reduce

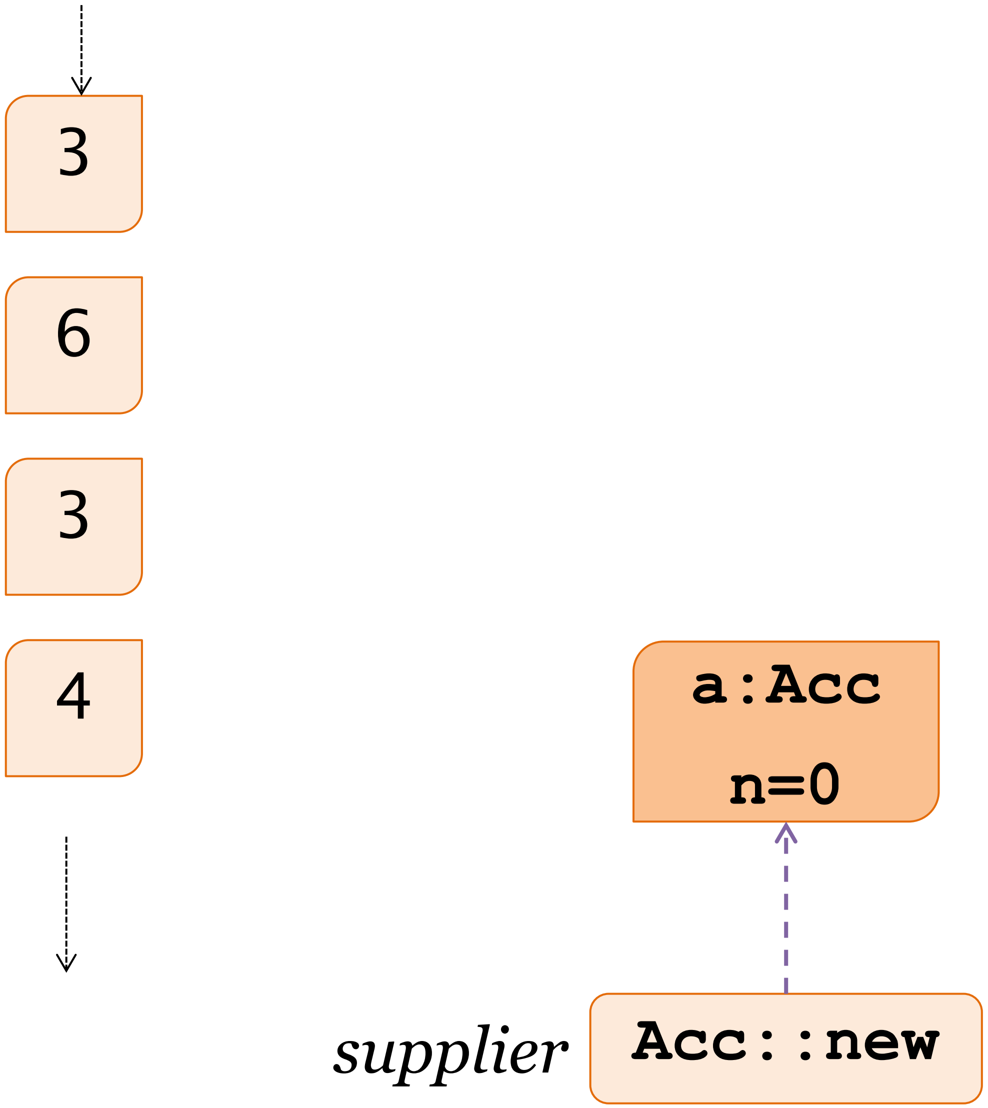


# Collecting

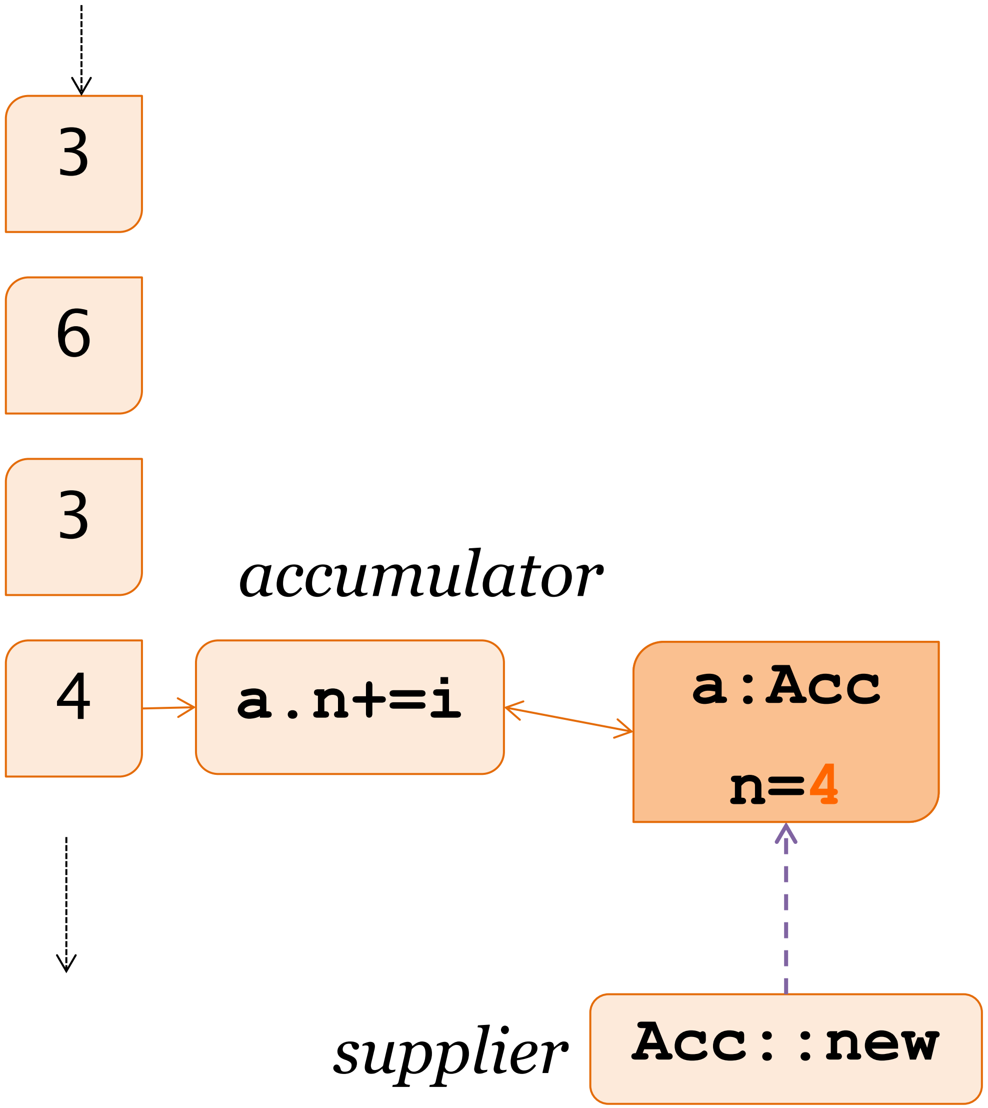
- `Stream.collect()` takes as argument a recipe for accumulating the elements of a stream into a summary result.
  - It is a stateful operation

```
class Acc { int n; }
int s = Stream.of(numbers).
 collect(Acc::new,                // supplier
         (a,i) -> a.n+=i,         // accumulator
         (a1,a2)->a1.n+=a2.n      // combiner
      ).n;
```

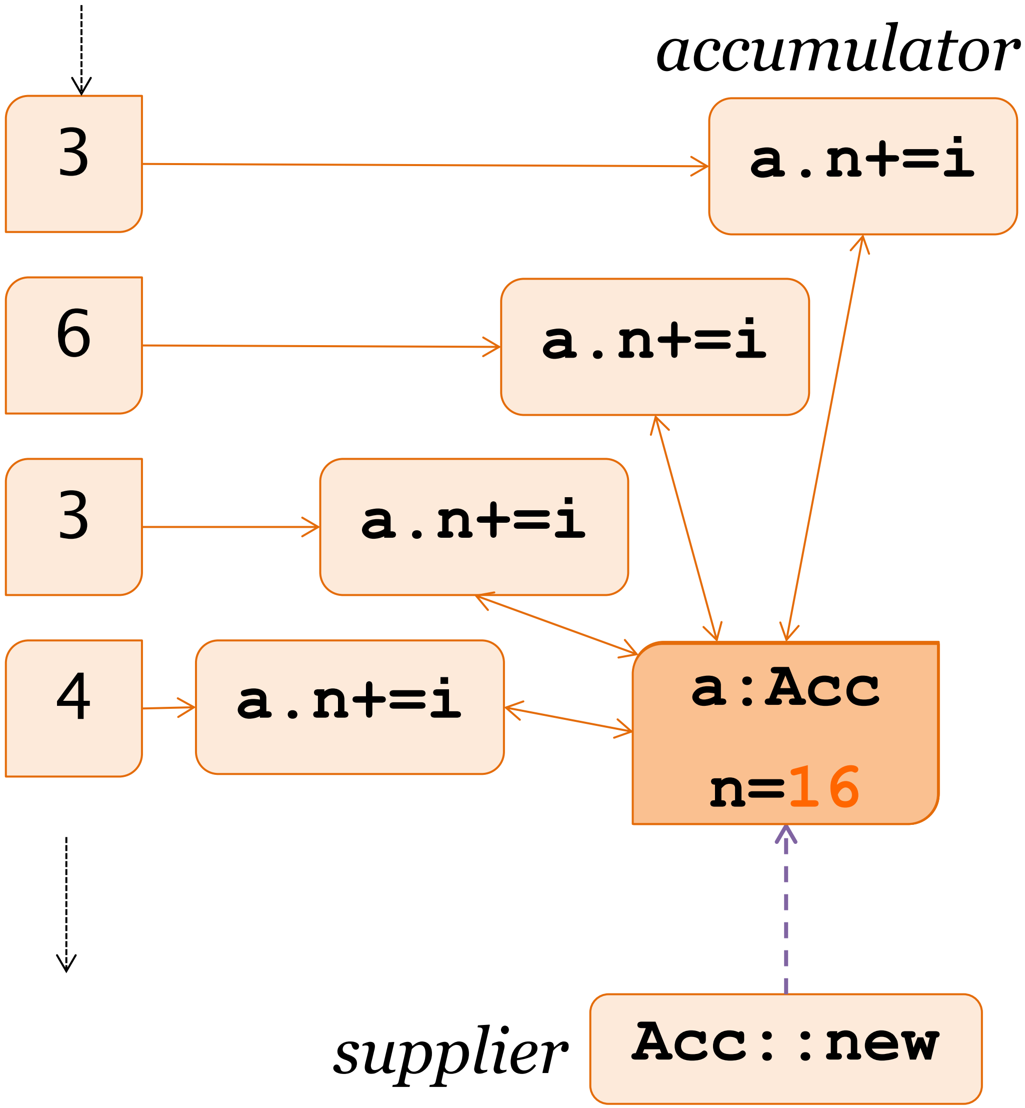
# Collecting



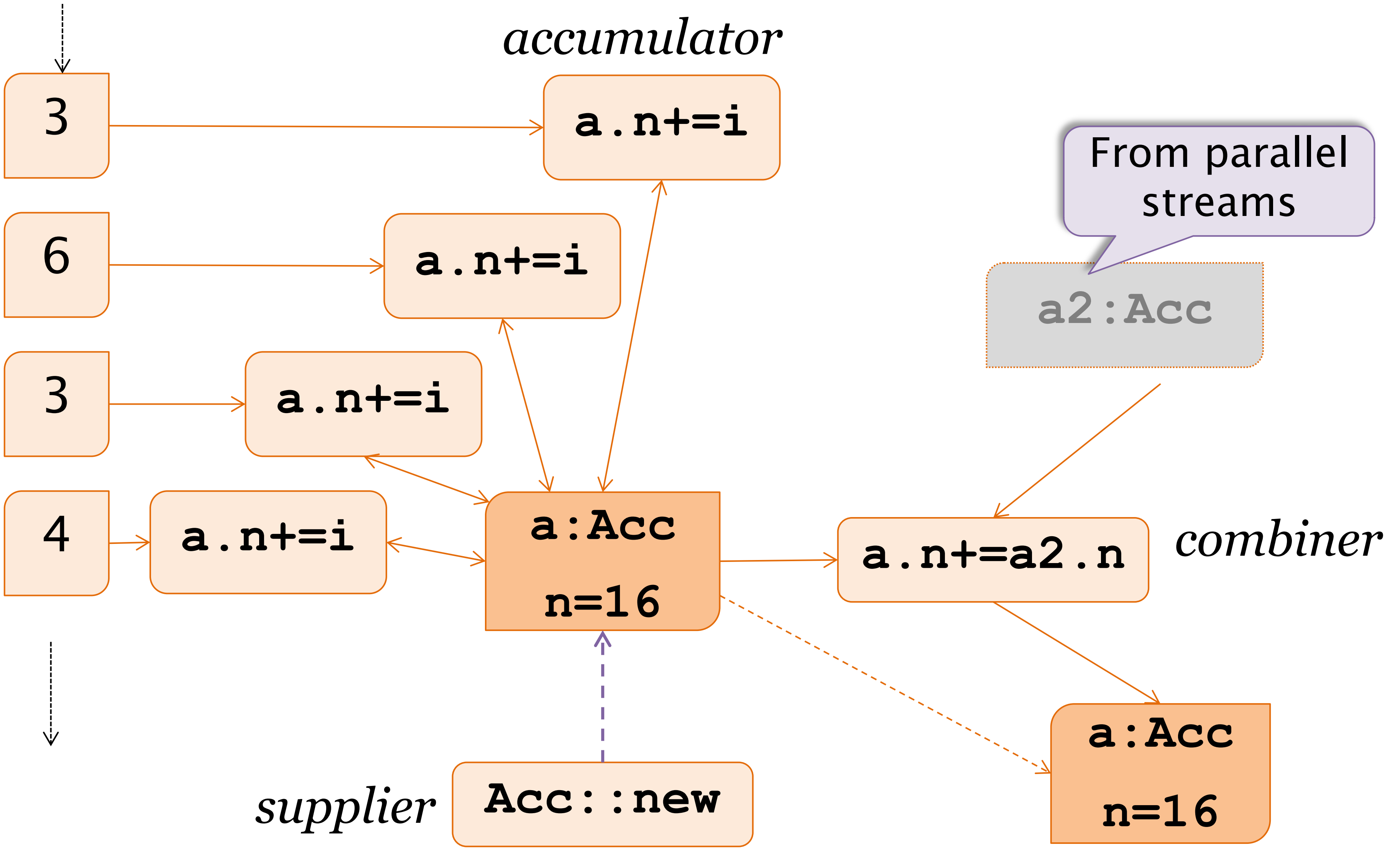
# Collecting



# Collecting



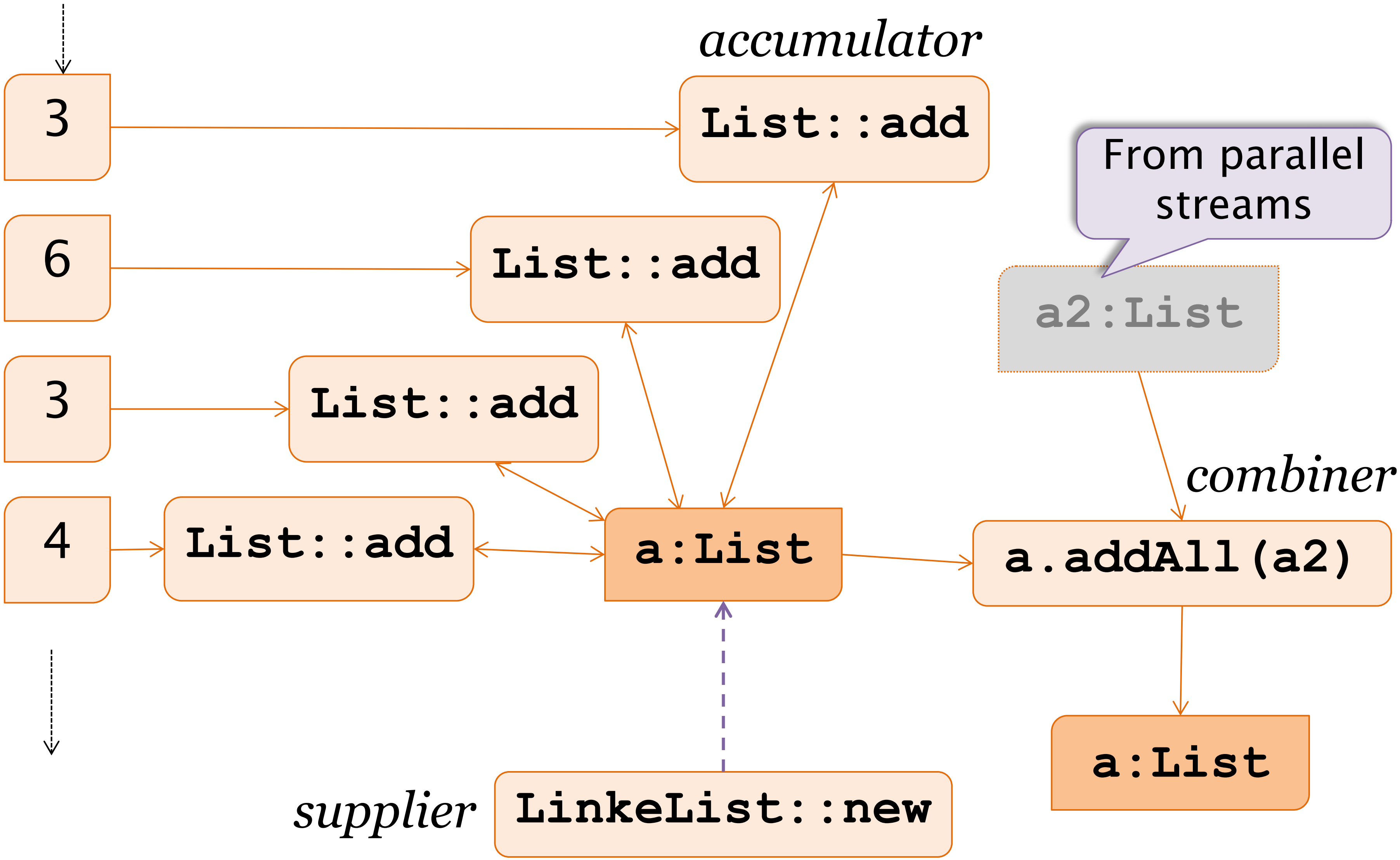
# Collecting


accumulator
3
6
3
4
a.n+=i
a.n+=i
a.n+=i
a.n+=i
From parallel streams
a2:Acc
a:Acc
n=16
a.n+=a2.n
combiner
a:Acc
n=16
supplier
Acc::new

# Collecting example

```
List<Integer> n = Stream.of(numbers).
collect(LinkedList::new,// supplier
        List::add,      // accumulator
        List::addAll);  // combiner
```

# Collecting



accumulator
3
List::add
6
List::add
3
List::add
4
List::add
From parallel streams
a2:List
combiner
a:List
a.addAll(a2)
a:List
supplier
LinkeList::new

# Lazy evaluation

- Stream pipelines are built first
  - without performing any processing
- Then executed
  - In response to a terminal operation
- **`Supplier<T>`** is used to delay creation of objects until when required, e.g.:
  - Supplier argument in **`collect`** is a factory object as opposed to passing an already created accumulating object

# Collect vs. Reduce

- Reduce
  - Is bounded
  - The merge operation can be used to combine results from parallel computation threads
- Collect
  - Is unbounded
  - Combining results form parallel computation threads can be performed with the combiner

Java Stream API

# Predefined Collectors

# Predefined collectors

- Predefined recipes are returned by static methods in **`Collectors`** class
  - Method are easier to access through:

```
import static java.util.stream.Collectors.*;
```

```
double averageWord = Stream.of(txta)
    .collect(averagingInt(String::length));
```

# Summarizing Collectors

| Collector | Return | Purpose |
|---|---|---|
| `counting()` | `long` | Count number of elements in stream |
| `maxBy() / minBy()` | `T` (elements type) | Find the min/max according to given Comparator |
| `summing`*Type*`()` | *Type* | Sum the elements |
| `averaging`*Type*`()` | *Type* | Compute arithmetic mean |
| `summarizing`*Type*`()` | *Type*`Summary-Statistics` | Compute several summary statistics from elements |

*Type* can be `Int`, `Long`, or `Double`

# Accumulating Collectors

| Collector | Return | Purpose |
|---|---|---|
| **`toList()`** | **`List<T>`** | Accumulates into a new **`List`** |
| **`toSet()`** | **`Set<T>`** | Accumulates into a new **`Set`** (i.e. discarding duplicates) |
| **`toCollection (Supplier<> cs)`** | **`Collection<T>`** | Accumulate into the collection provided by given **`Supplier`** |
| **`joining()`** | **`String`** | Concatenates into a **`String`** Optional arguments: separator, prefix, and postfix |

# Group container collectors

- Returns the three longest words in text:

```
List<String> longestWords = Stream.of(txta)
.filter( w -> w.length()>10)
.distinct()
.sorted(comparing(String::length).reversed())
.limit(3)
.collect(toList());
```

What if two words share the 3rd position?

# Grouping Collectors

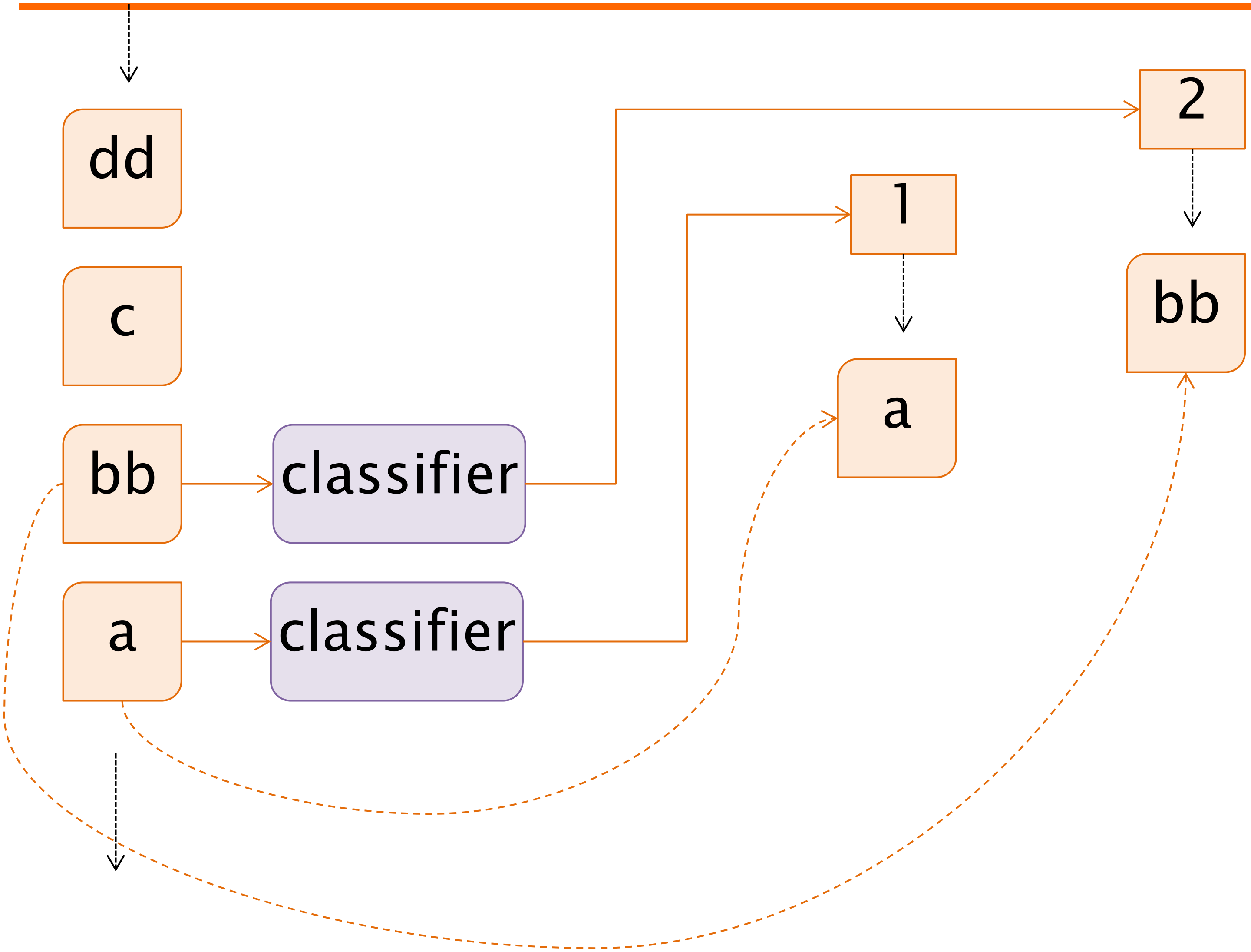
| Collector | Return | Purpose |
|---|---|---|
| **`groupingBy (Function<T,K> classifier)`** | **`Map<K, List<T>>`** | Map according to the key extracted (by **`classifier`**) and add to list.<br><br>Optional arguments:<br>– Downstream Collector (nested)<br>– Map factory supplier |
| **`partitioningBy (Function<T, Boolean> p)`** | **`Map<Boolean, List<T>>`** | Split according to partition function (**`p`**) and add to list.<br><br>Optional arguments:<br>– Downstream Collector (nested)<br>– Map supplier |

# Example: grouping collectors

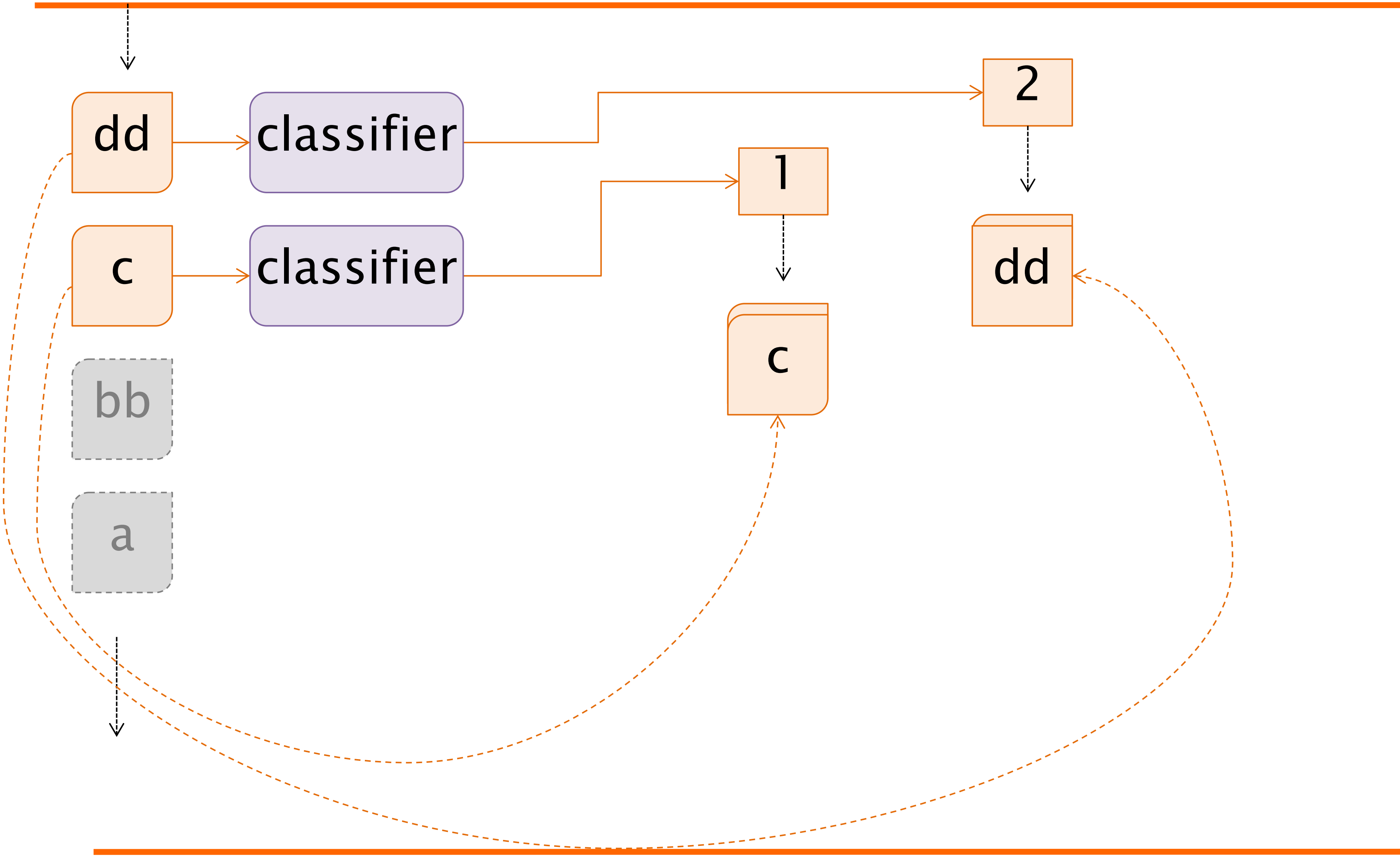
- Grouping by feature

```
Map<Integer,List<String>> byLength =
   Stream.of(txta).distinct()
   .collect(groupingBy(String::length));
```

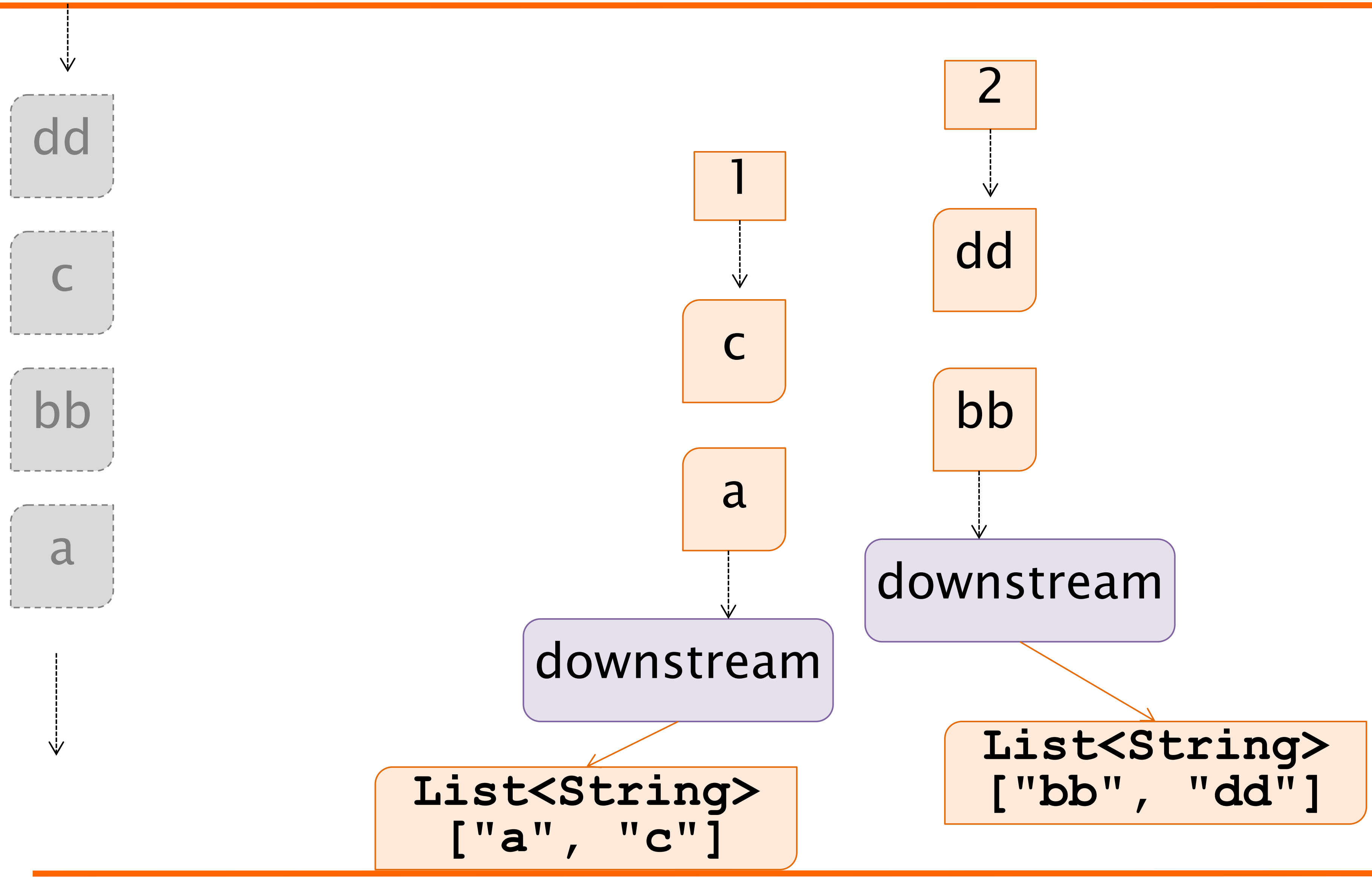
# Grouping Collector



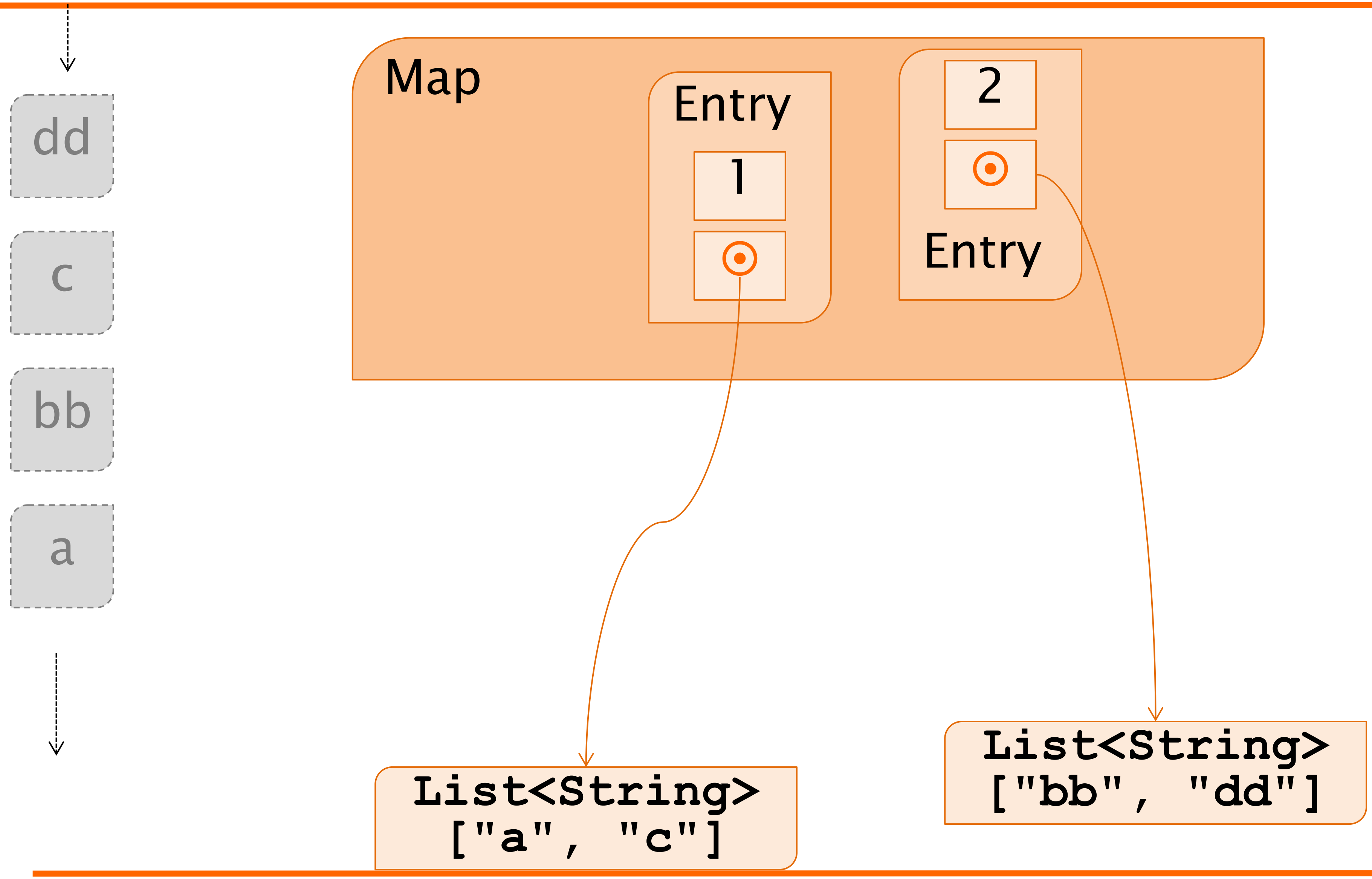
# Grouping Collector



# Grouping Collector



# Grouping Collector



# Example: grouping collectors

- Sorted grouping by feature

```
Map<Integer,List<String>> byLength =
Stream.of(txta).distinct()
.collect(groupingBy(String::length,
            ()-> new TreeMap<>(reverseOrder()),
            toList()))
```

Map sorted by descending length

# Example: grouping collectors

- Grouping and counting

```
Map<String,Long> frequency =
Stream.of(txta)
.collect(groupingBy(
            w->w,
            counting()));
```

Grouped by word

Downstream is counting

# Example: grouping collectors

- Stream of map entries:

```
List<String> freqSorted =
Stream.of(txta)
.collect(groupingBy(w->w, counting()))
.entrySet().stream()
.sorted(
   comparing(Map.Entry<String,Long>::getValue)
   .reversed()
   .thenComparing(Map.Entry::getKey))
.map( e -> e.getValue() + ":" + e.getKey())
.collect(toList());
```

# Collector Composition

| Collector | Purpose |
| --- | --- |
| `collectingAndThen (Collector<T,?,R> cltr, Function<R,RR> mapper)` | Apply a transformation (**`mapper`**) after performing collection (**`cltr`**) |
| `mapping (Function<T,U> mapper, Collector<U,?,R> cltr)` | Performs a transformation (**`mapper`**) before applying the collector (**`cltr`**) |

# Example: grouping collectors

- Re-open the map entry set:

```
List<String> longestWords =
Stream.of(txta).distinct()
.collect(collectingAndThen(
                                                  collecting
      groupingBy(String::length,
         ()->new TreeMap<>(reverseOrder()),
         toList())
      ,
                                                    and then
      m -> m.entrySet().stream()
         .limit(3)
         .flatMap(e->e.getValue().stream())
         .collect(toList()) );
```

# Example: collecting and then

- Stream of map entries:

```
Stream.of(txta)
.collect(collectingAndThen(
    groupingBy(w->w, counting())          collecting
,
    m->m.entrySet().stream()              and then
    .sorted(comparing(Map.Entry::getValue))
    .map(e->e.getValue()+ ":" +e.getKey())
    .collect(toList())))
```

# Example: mapping

- Stream of map entries:

```
Stream.of(txta)
.collect(collectingAndThen(
   groupingBy( w->w, counting())
,
   m->m.entrySet().stream()
   .collect(groupingBy(
       Map.Entry::getValue,
       mapping(Map.Entry::getKey,
          toList())))));
```

# Custom collectors

# Collector

T : element

A : accumulator

R : result

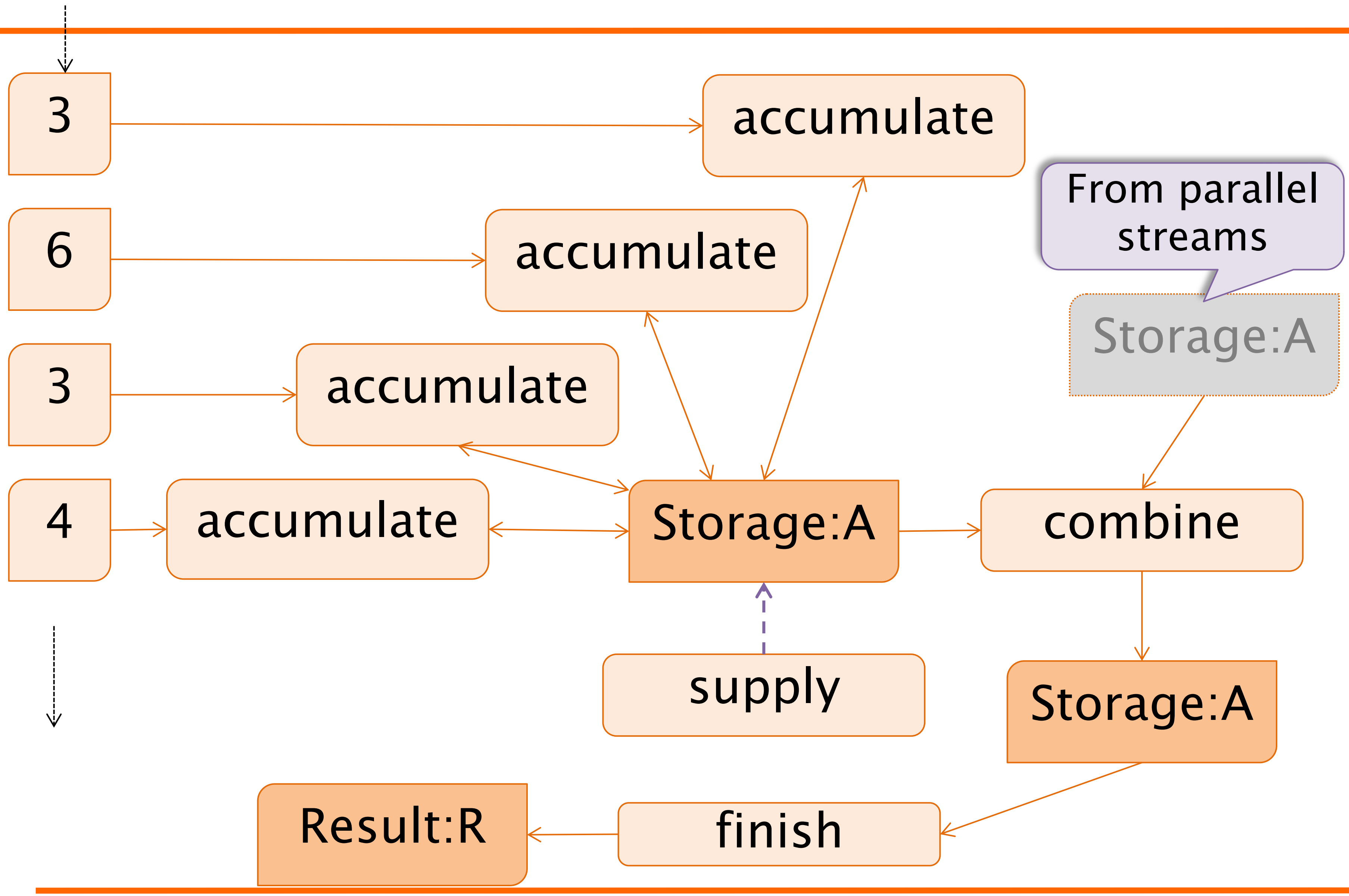
```
interface Collector<T,A,R>{
```

- `Supplier<A> supplier()`
  - Creates the accumulator container
- `BiConsumer<A,T> accumulator();`
  - Adds a new element into the container
- `BinaryOperator<A> combiner();`
  - Combines two containers (used for parallelizing)
- `Function<A,R> finisher();`
  - Performs a final transformation step
- `Set<Characteristics> characteristics();`
  - Capabilities of this collector

```
}
```

Operator, not consumer!

# Collecting



3
6
3
4
accumulate
accumulate
accumulate
accumulate
From parallel streams
Storage:A
Storage:A
combine
supply
Storage:A
Result:R
finish

# `Collector.of`

```
static Collector<T,A,R> of(
    Supplier<A> supplier,
    BiConsumer<A,T> accumulator,
    BinaryOperator<A> combiner,
    Function<A,R> finisher,
    Characteristic... characts)
```

optional

- More compact form than extending interface `Collector`

# Collector.of

```
Collector<String,List<String>,List<String>>
toList = Collector.of(
  ArrayList::new,
  List::add,
  (a,b)->{a.addAll(b);return a;}
);
```

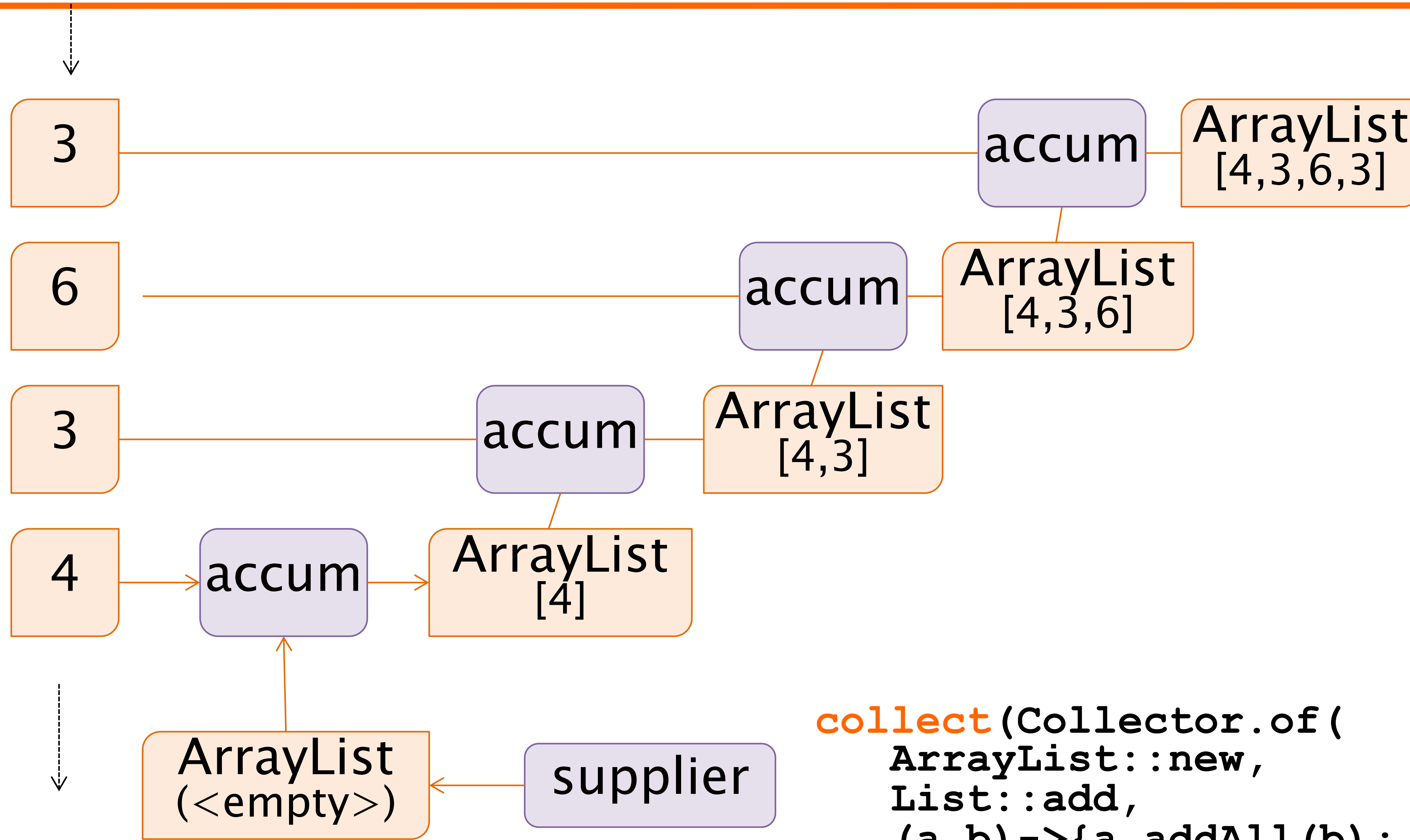
supplier

accumulator

combiner

Implicit finisher => identity transformation
No characteristics

# Collector




```
collect(Collector.of(
    ArrayList::new,
    List::add,
    (a,b)->{a.addAll(b);
             return a;}))
```

# Collector example

- More compact form:

```
String listOfWords = Stream.of(txta)
.map(String::toLowerCase)
.distinct()
.sorted(comparing(String::length).reversed())
.collect(Collector.of(
        ArrayList::new,
        List::add,
        (a,b) -> { a.addAll(b); return a; },
        List::toString));
```

supplier

accumulator

combiner

finisher

# Characteristics

- **`IDENTITY_FINISH`**
  - Finisher function is the identity function therefore it can be elided
- **`CONCURRENT`**
  - Accumulator function can be called concurrently on the same container
- **`UNORDERED`**
  - The operation does require stream elements order to be preserved

# Characteristics

- Characteristics can be used to optimize execution
- If both **`CONCURRENT`** and **`UNORDERED`**, then, when operating in parallel,
  - Accumulator method is invoked concurrently by several threads
  - Combiner is not used

# Collector and accumulator

- Collector used to compute the average length of a stream of String
  - Uses the **`AverageAcc`** accumulator object

```
Collector<Integer,AverageAcc,Double>
avgCollector = Collector.of(
        AverageAcc::new,     // supplier
        AverageAcc::addWord,// accumulator
        AverageAcc::merge , // combiner
        AverageAcc::average // finisher
);
```

# Average Accumulator

```
class AverageAcc {
   private long length;
   private long count;
   public void addWord(String w){
      this.length+=w.length();// accumulator
      count++;  }
   public double average(){    // finisher
      return length*1.0/count; }
   public AverageAcc merge(AverageAcc o){
      this.length+=other.length;
      this.count+=other.count;  // combiner
      return this;}
}
```

# Summary

- Streams provide a powerful mechanism to express computations of sequences of elements
- The operations are optimized and can be parallelized
- Operations are expressed using a functional notation
  - More compact and readable w.r.t. imperative notation