

Parallel & Asynchronous Programming In Modern Java

Dilip Sundarraaj

About Me

- Dilip
- Building Software's since 2008
- Teaching in **UDEMY** Since 2016

What's Covered ?

- Need for Parallel and Asynchronous Programming
- Covers the **ParallelStreams and CompletableFuture API**
- Techniques to write **Fast Performing Code using Functional Style Concurrency APIs** in Java
- Covers Best Practices using **ParallelStreams/CompletableFuture API** in your code
- NonBlocking RestFul API Client using **CompletableFuture API**
- Testing ParallelStreams and CompletableFuture API Using **JUnit5**

Targeted Audience

- Experienced Java Developers
- Developers who has the need to write code that executes faster
- Developers who has the need to write code that executes in **Parallel**
- Developer who has the need to write asynchronous/non-blocking code

Source Code

Thank You!

Prerequisites

Course Prerequisites

- Java 11

- Prior Java

- Experience

- Experience

- IntelliJ ,

Development > Programming Languages > Java

Modern Java - Learn Java 8 features by coding it

Learn Lambdas, Streams , new Date APIs, Optionals and Parallel programming in Java 8 by coding it.

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Wishlist ❤️

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- ✓ Learn Functional programming in Java
- ✓ Students will be able to implement the new Java 8 concepts in real time
- ✓ Learn the new Date/Time Libraries in Java 8
- ✓ Learn and understand Parallel Programming with the Streams.
- ✓ This course will be continuously updated.
- ✓ Complete understanding of Lambdas, Streams , Optional via code.
- ✓ Learn to build complex Streams Pipeline.
- ✓ Learn to use Method Reference , Constructor reference syntax.
- ✓ Student will be able to upgrade their Java knowledge with the new Functional Features.



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Why Parallel and Asynchronous Programming ?

Why Parallel and Asynchronous Programming?

- We are living in a fast paced environment
- In Software Programming:
 - Code that we write should execute faster
- Goal of Asynchronous and Parallel Programming
 - Provide Techniques to improve the performance of the code

Technology Advancements

Hardware

- Devices or computers comes up with Multiple cores
- Developer needs to learn programming patterns to maximize the use of multiple cores
- Apply the Parallel Programming concepts
- **Parallel Streams**

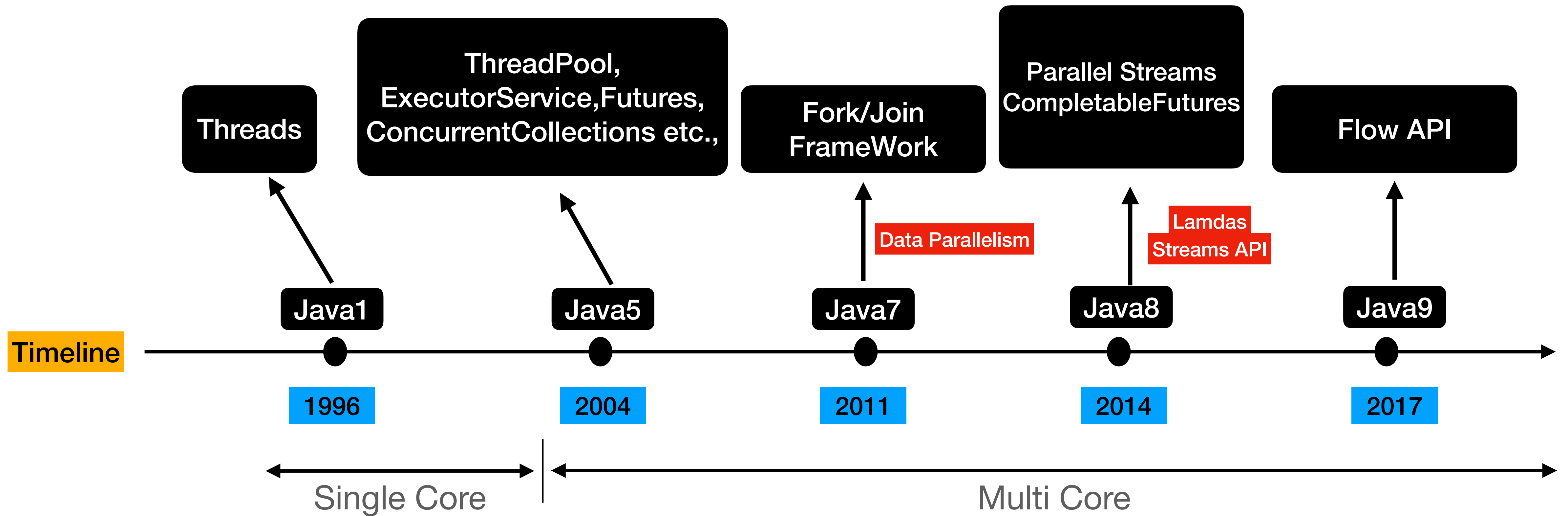
Threads

Software

- MicroServices Architecture style
- Blocking I/O calls are common in MicroServices Architecture. This also impacts the latency of the application
- Apply the Asynchronous Programming concepts
- **CompletableFuture**

Functional Style of Programming

Evolution of Concurrency and Parallelism APIs in Java



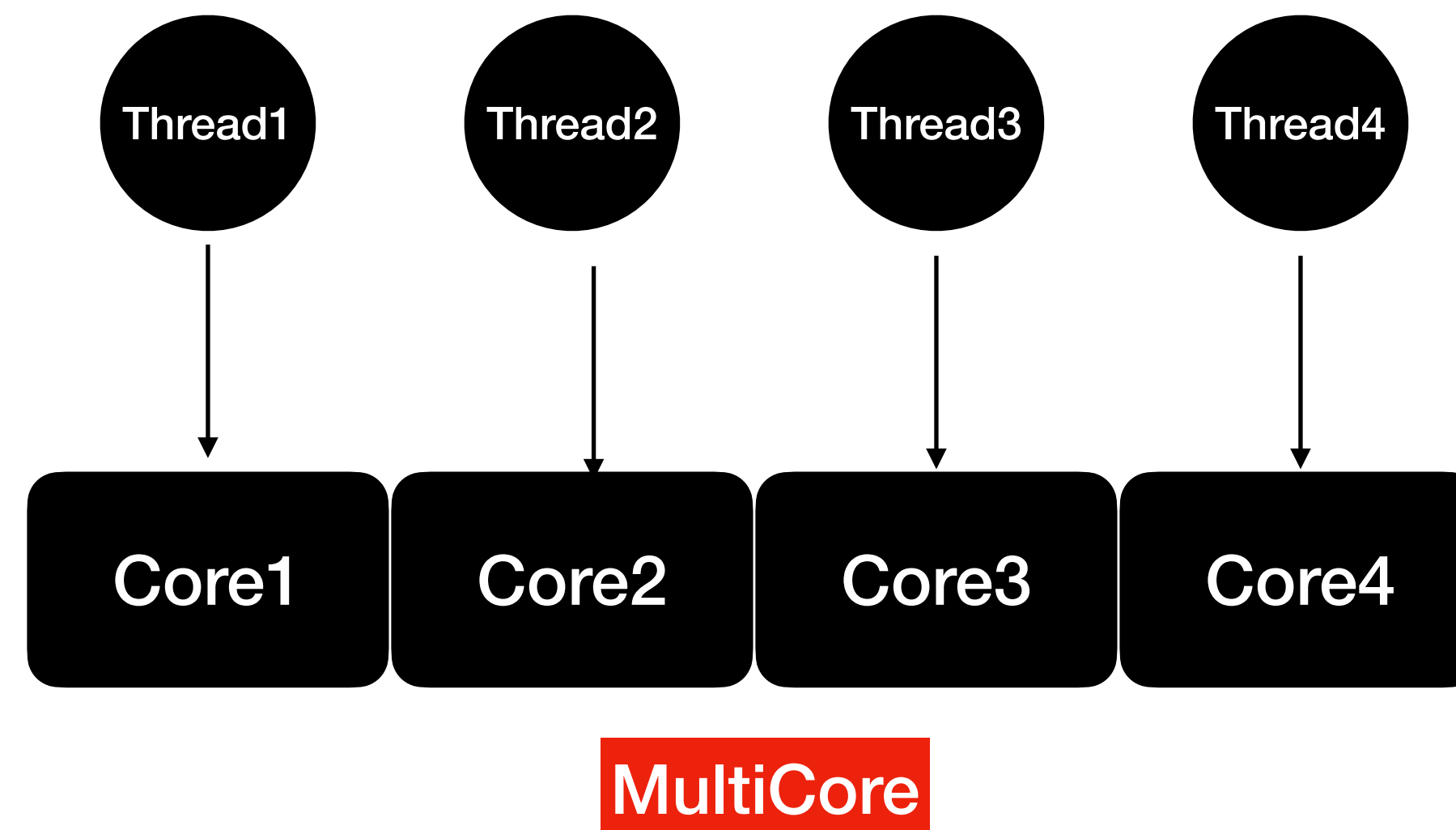
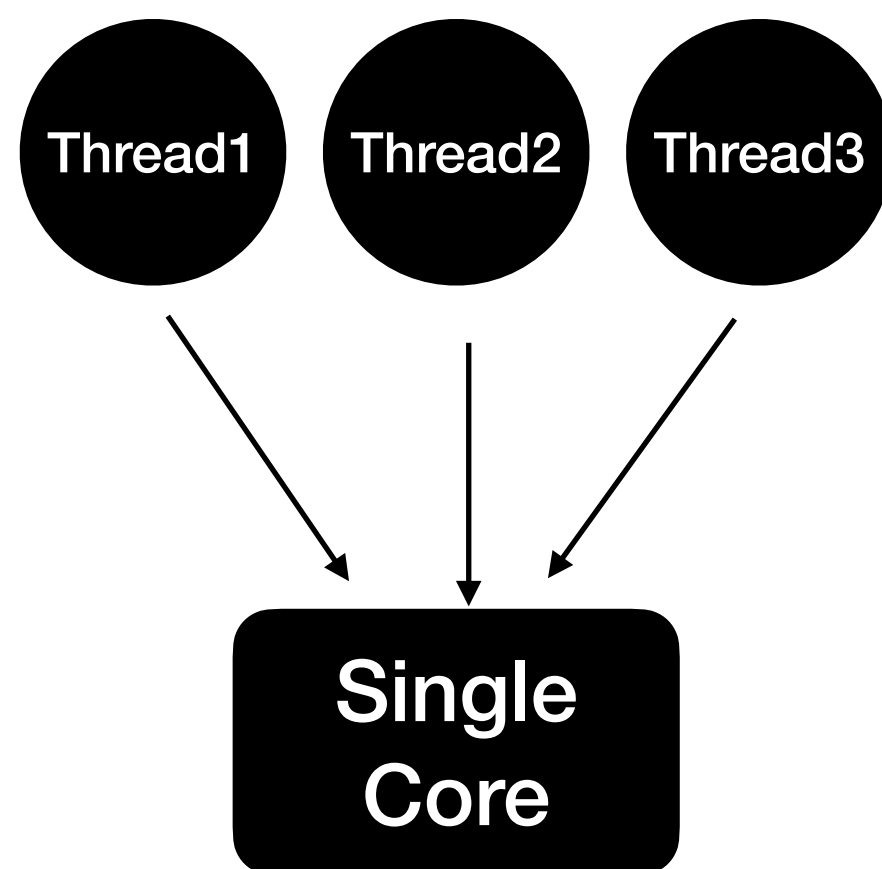
Current Version : Java14

https://en.wikipedia.org/wiki/Java_version_history

Concurrency vs Parallelism

Concurrency

- Concurrency is a concept where two or more task can run simultaneously
- In Java, Concurrency is achieved using **Threads**
 - Are the tasks running in interleaved fashion?
 - Are the tasks running simultaneously ?



Concurrency Example

- In a real application, Threads normally need to interact with one another
 - Shared Objects or Messaging Queues
- Issues:
 - Race Condition
 - DeadLock and more
- Tools to handle these issues:
 - Synchronized Statements/Methods
 - Reentrant Locks, Semaphores
 - Concurrent Collections
 - Conditional Objects and More

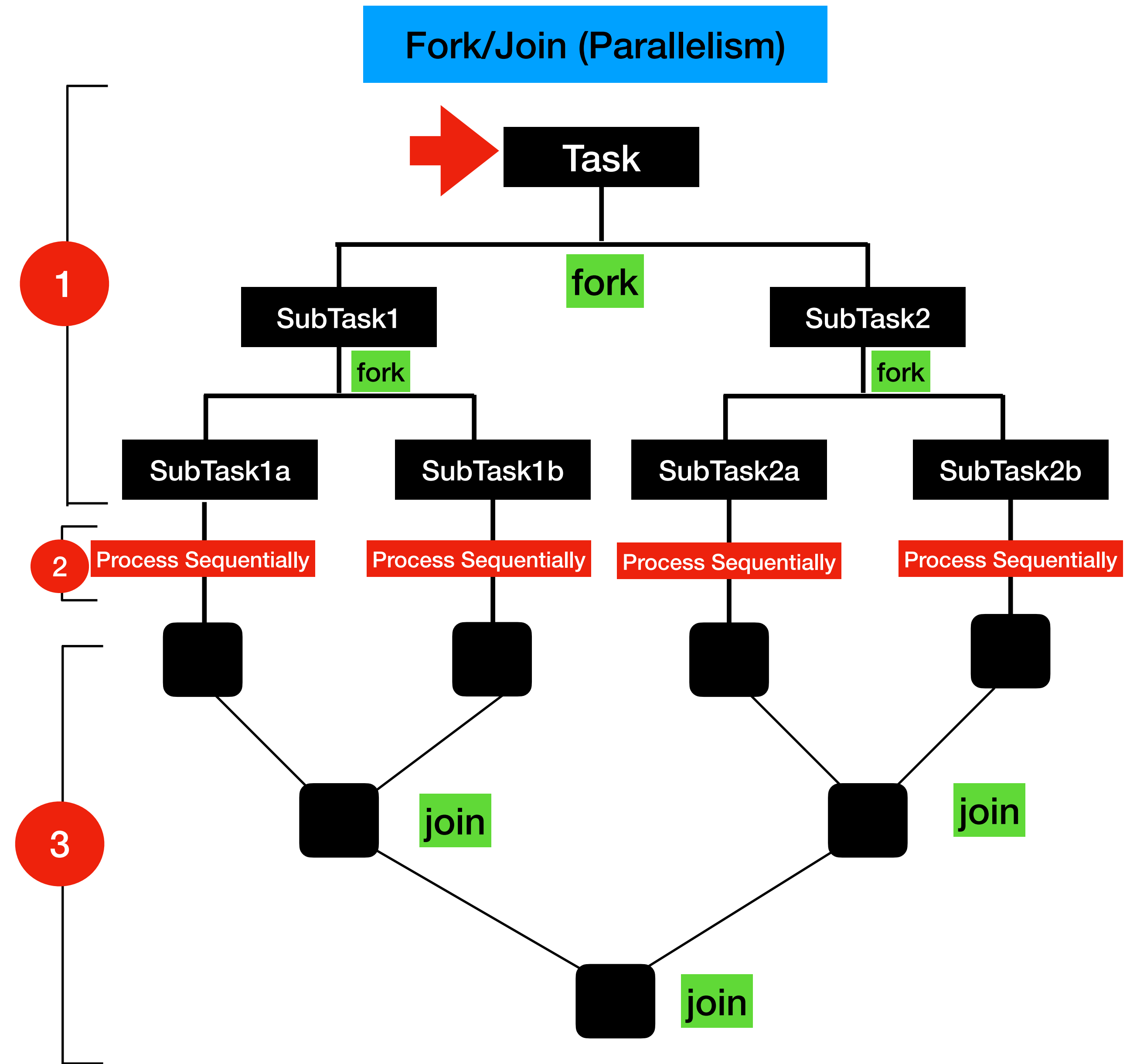
```
public class HelloWorldThreadExample {  
    private static String result="";  
  
    private static void hello(){  
        delay(500);  
        result = result.concat("Hello");  
    }  
    private static void world(){  
        delay(600);  
        result = result.concat(" World");  
    }  
  
    public static void main(String[] args) throws InterruptedException {  
        1 Thread helloThread = new Thread(()-> hello());  
          Thread worldThread = new Thread(()-> world());  
        2 //Starting the thread  
          helloThread.start();  
          worldThread.start();  
        3 //Joining the thread (Waiting for the threads to finish)  
          helloThread.join();  
          worldThread.join();  
  
          System.out.println("Result is : " + result);  
    }  
}
```

Threads

↓
Hello World

Parallelism

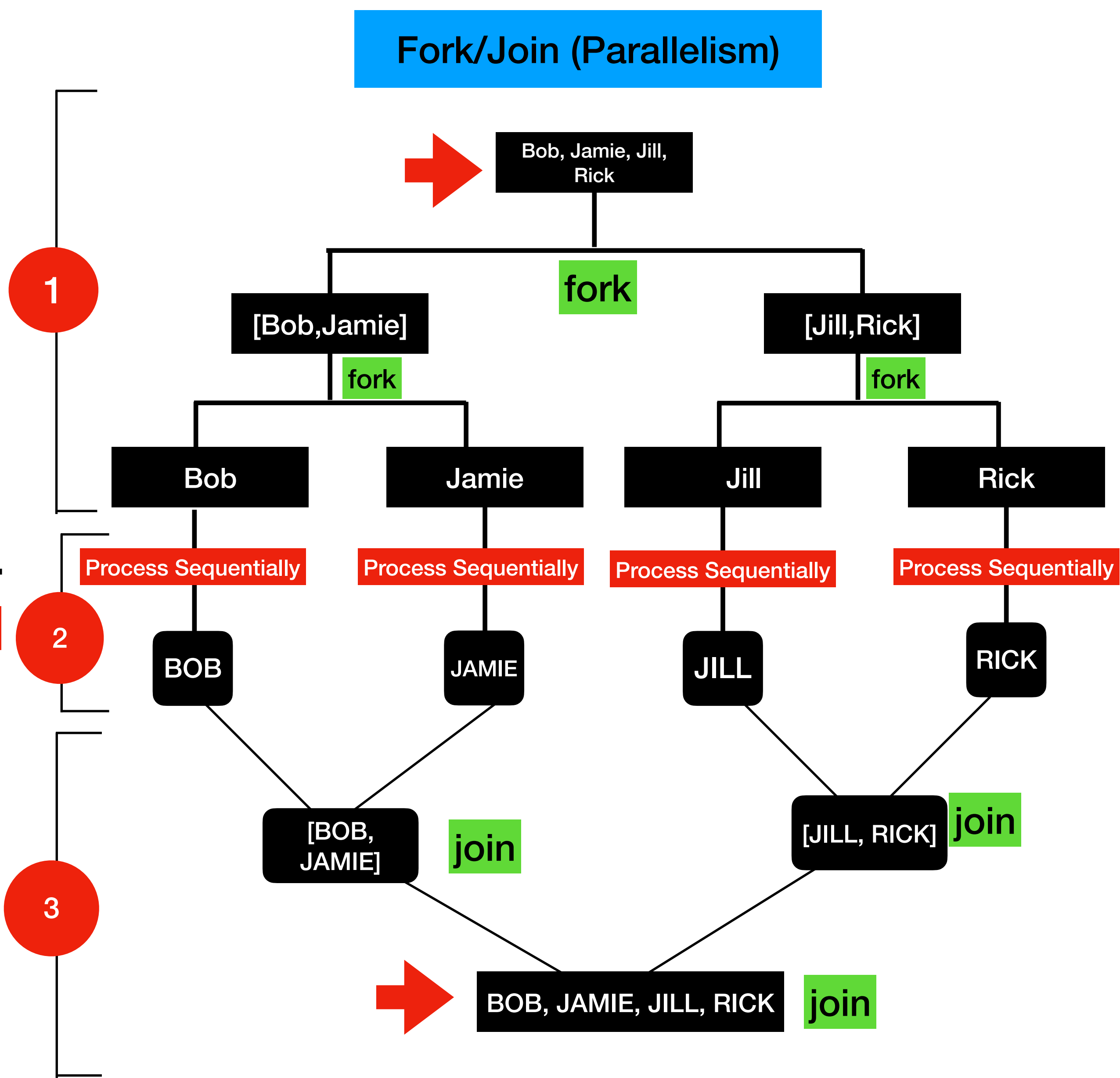
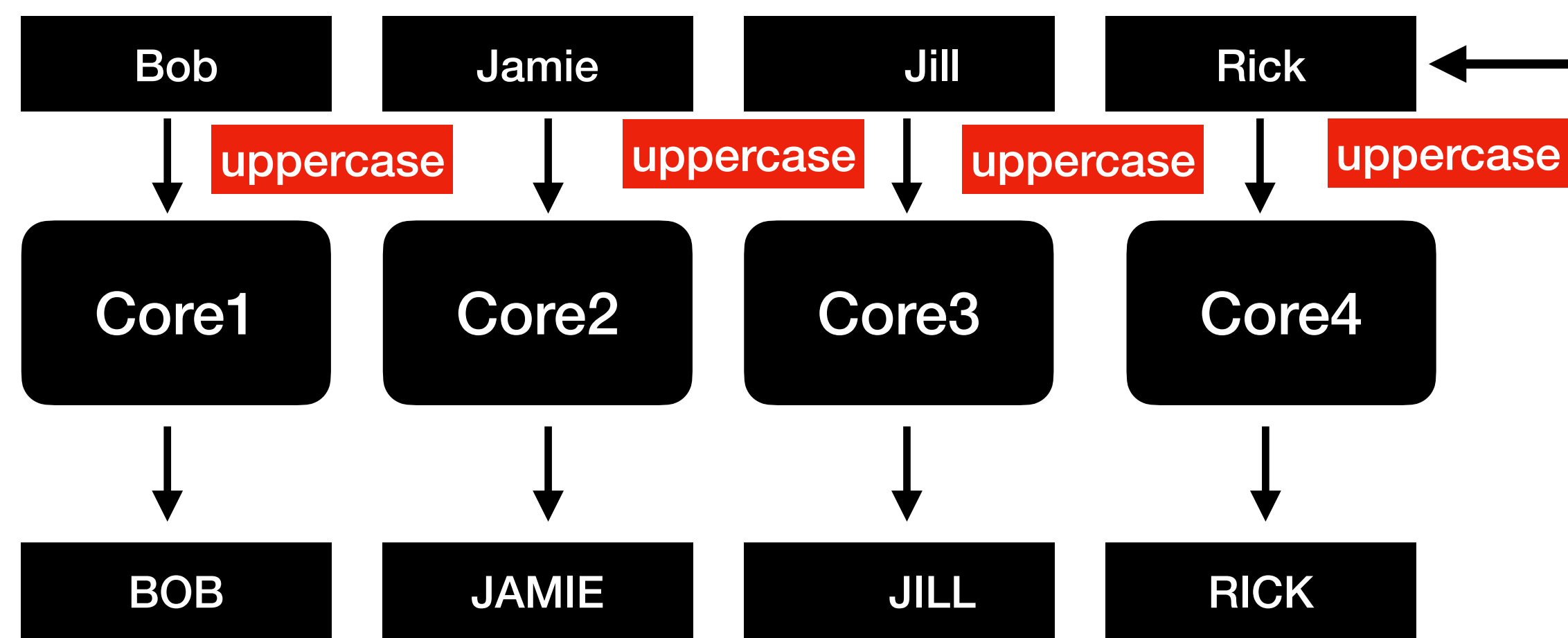
- Parallelism is a concept in which tasks are literally going to run in parallel
- Parallelism involves these steps:
 - Decomposing the tasks in to SubTasks(Forking)
 - Execute the subtasks in sequential
 - Joining the results of the tasks(Join)
- Whole process is also called **Fork/Join**



Parallelism Example

UseCase: Transform to UpperCase

[Bob, Jamie, Jill, Rick] -> [BOB, JAMIE, JILL, RICK]



Parallelism Example

```
public class ParallelismExample {  
    public static void main(String[] args) {  
        List<String> namesList = List.of("Bob", "Jamie", "Jill", "Rick");  
        System.out.println("namesList : " + namesList);  
        List<String> namesListUpperCase = namesList  
            .parallelStream() ←  
            .map(String::toUpperCase) ←  
            .collect(Collectors.toList());  
  
        System.out.println("namesListUpperCase : " + namesListUpperCase);  
    }  
}
```

Concurrency vs Parallelism

- Concurrency is a concept where two or more tasks can run in simultaneously
- Concurrency can be implemented in single or multiple cores
- Concurrency is about correctly and efficiently controlling access to shared resources
- Parallelism is a concept where two or more tasks are literally running in parallel
- Parallelism can only be implemented in a multi-core machine
- Parallelism is about using more resources to access the result faster

Course Project Setup

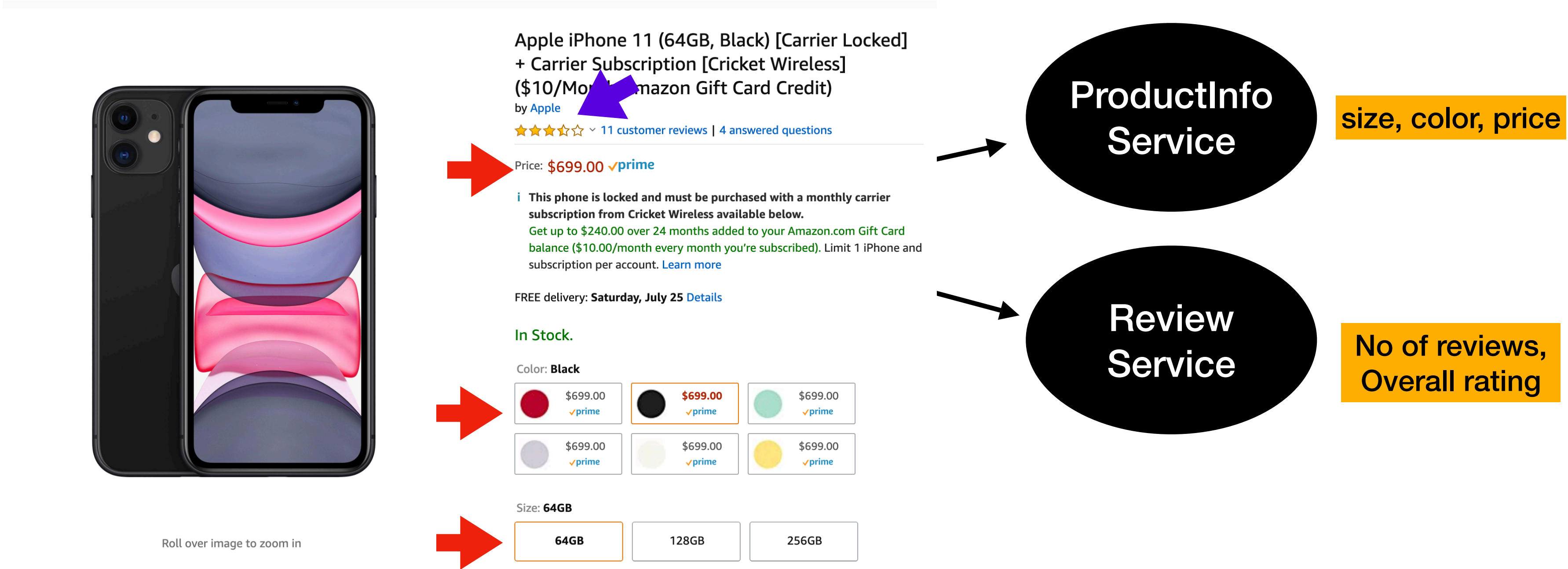
Section Overview

Section Overview

- Covers Asynchronous and Parallel Programming prior Java 8
- Threads, Futures and ForkJoin Framework and its limitations
- Covers Theory and Hands On

Overview of the Product Service

Product Service



Threads

Threads API

- Threads API got introduced in Java1
- Threads are basically used to offload the blocking tasks as **background** tasks
- Threads allowed the developers to write asynchronous style of code

Thread API Limitations

- Requires a lot of code to introduce asynchrony
 - Runnable, Thread
 - Require additional properties in Runnable
 - Start and Join the thread
- Low level
- Easy to introduce complexity in to our code

ThreadPool, ExecutorService & Future

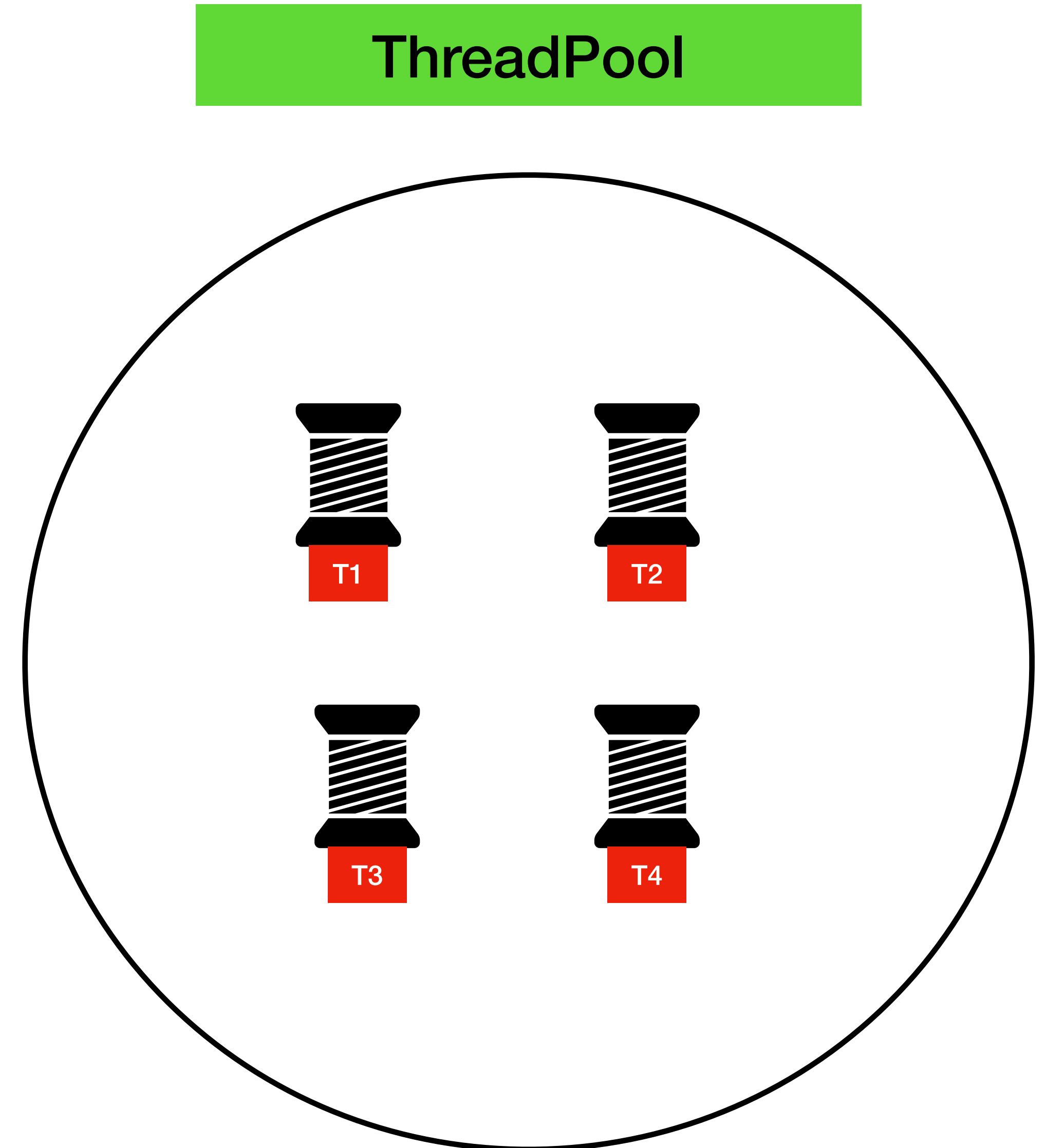
Limitations Of Thread

- Limitations of Thread:
 - Create the thread
 - Start the thread
 - Join the thread
- Threads are expensive
 - Threads have their own runtime-stack, memory, registers and more

Thread Pool was created specifically to solve this problem

Thread Pool

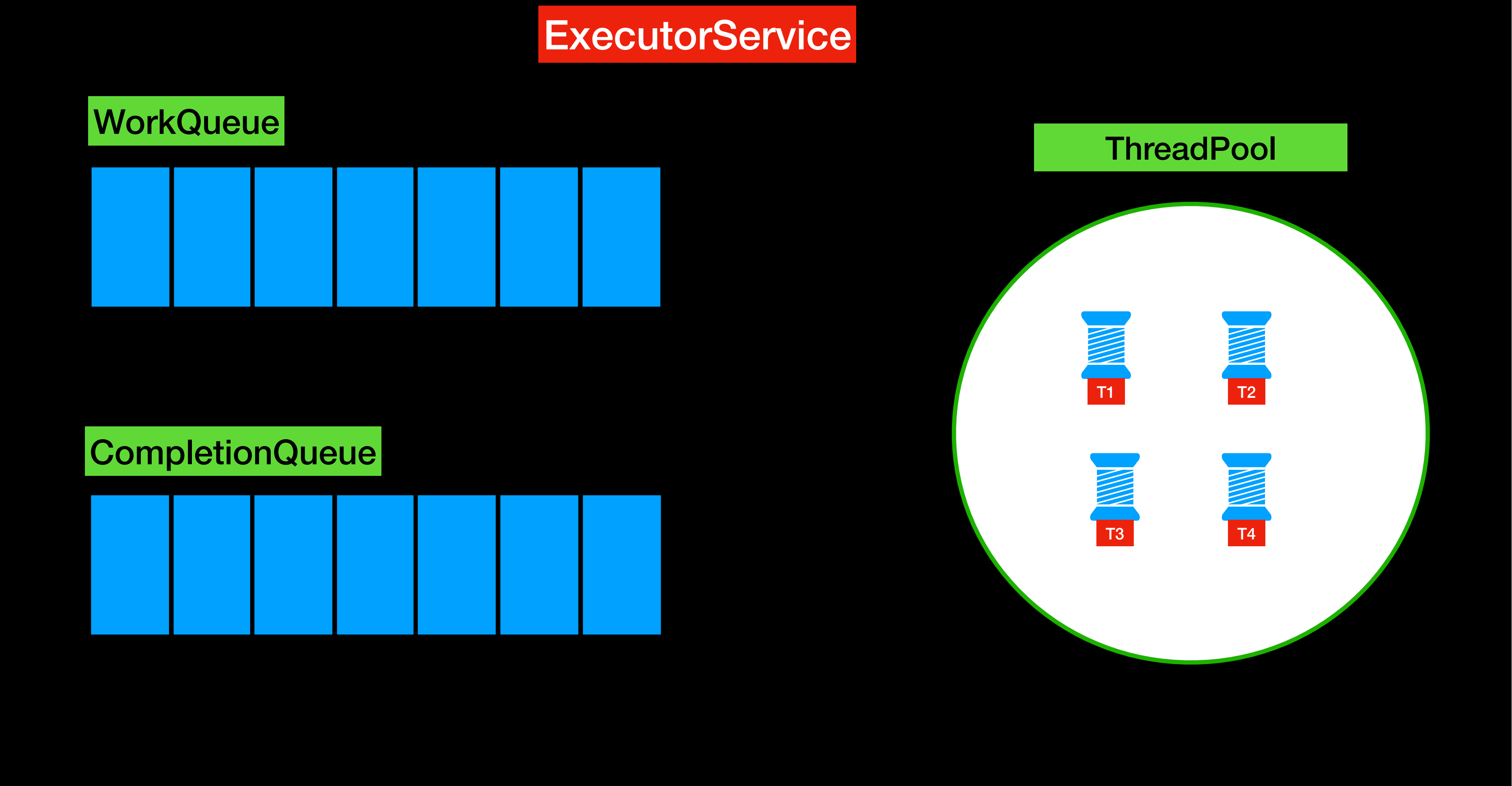
- Thread Pool is a group of threads created and readily available
- CPU Intensive Tasks
 - ThreadPool Size = No of Cores
- I/O task
 - ThreadPool Size > No of Cores
- What are the benefits of thread pool?
 - No need to manually create, start and join the threads
 - Achieving Concurrency in your application



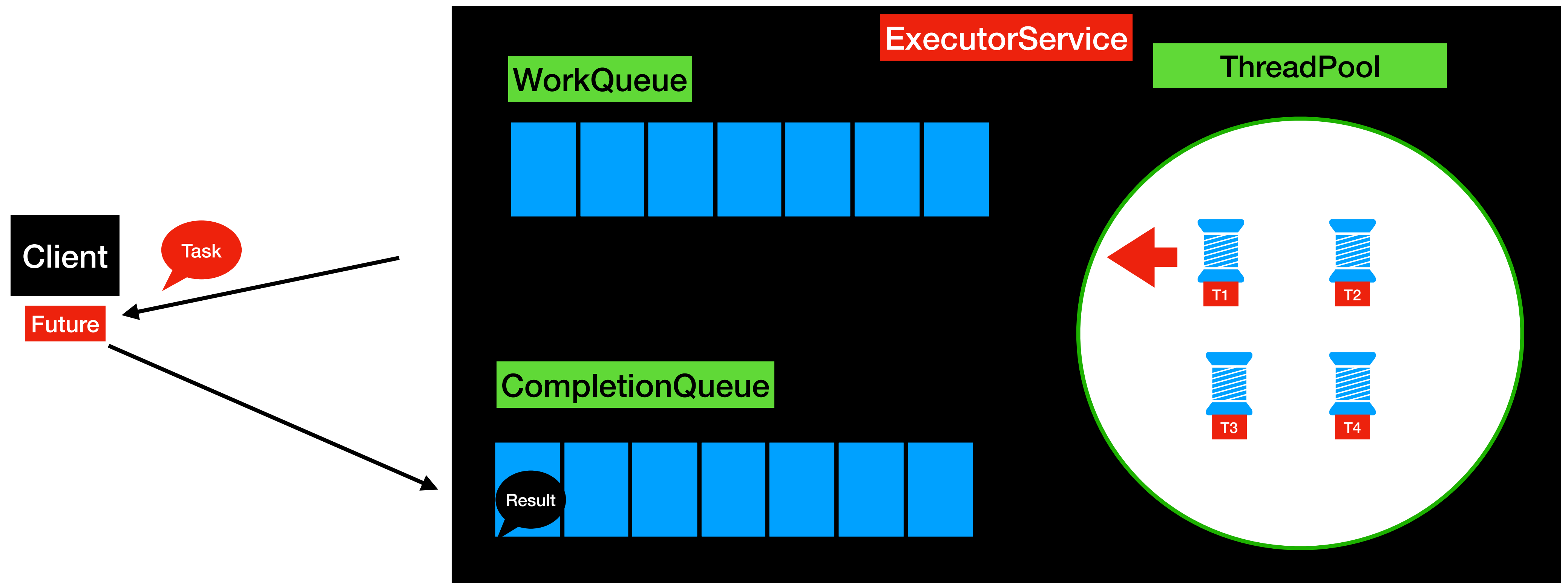
ExecutorService

- Released as part of Java5
- ExecutorService in Java is an **Asynchronous Task Execution Engine**
- It provides a way to asynchronously execute tasks and provides the results in a much simpler way compared to threads
- This enabled coarse-grained task based parallelism in Java

ExecutorService



Working Of ExecutorService



Limitations of ExecutorService

- Designed to Block the Thread

```
ProductInfo productInfo = productInfoFuture.get();  
Review review = reviewFuture.get();
```

- No better way to combine futures

```
ProductInfo productInfo = productInfoFuture.get();  
Review review = reviewFuture.get();  
return new Product(productId, productInfo, review);
```

Fork/Join Framework

Fork/Join Framework

- This got introduced as part of **Java7**
- This is an extension of **ExecutorService**
- Fork/Join framework is designed to achieve **Data Parallelism** 
- ExecutorService is designed to achieve **Task Based Parallelism**

```
Future<ProductInfo> productInfoFuture = executorService.submit(() -> productInfoService.retrieveProductInfo(productId));
```

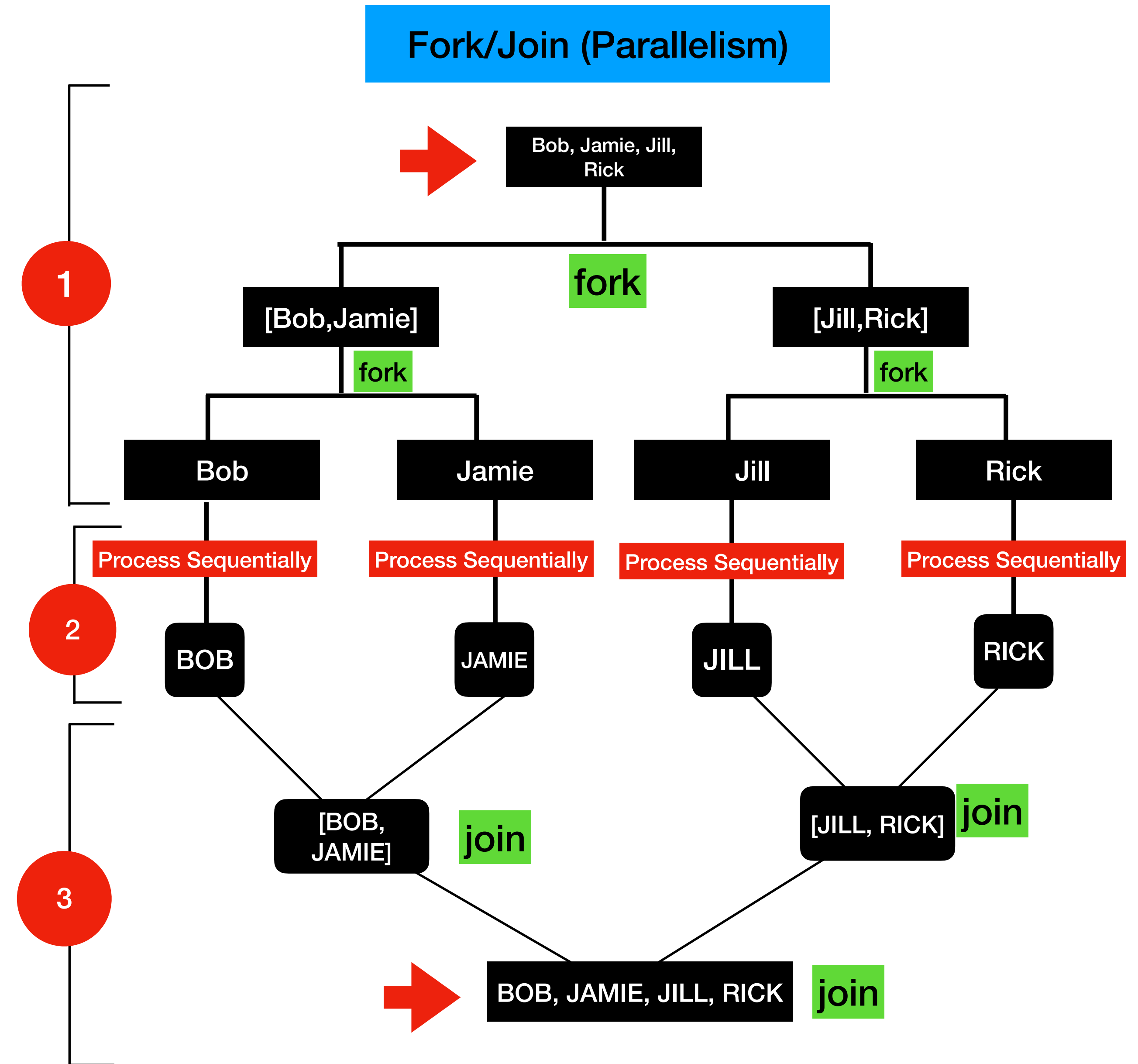


```
Future<Review> reviewFuture = executorService.submit(() -> reviewService.retrieveReviews(productId));
```



What is Data Parallelism ?

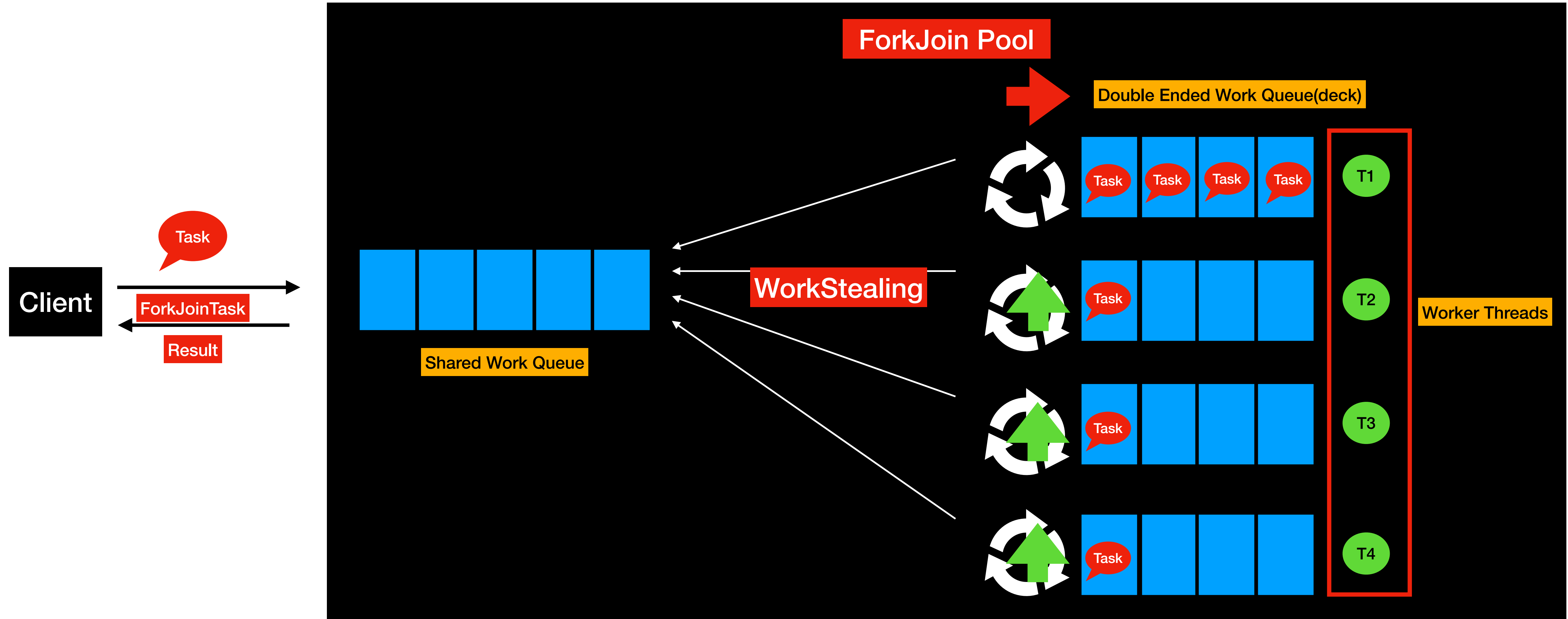
- Data Parallelism is a concept where a given **Task** is recursively split in to **SubTasks** until it reaches it leaset possible size and execute those tasks in parallel
- Basically it uses the **divide and conquer** approach



How does Fork/Join Framework Works ?

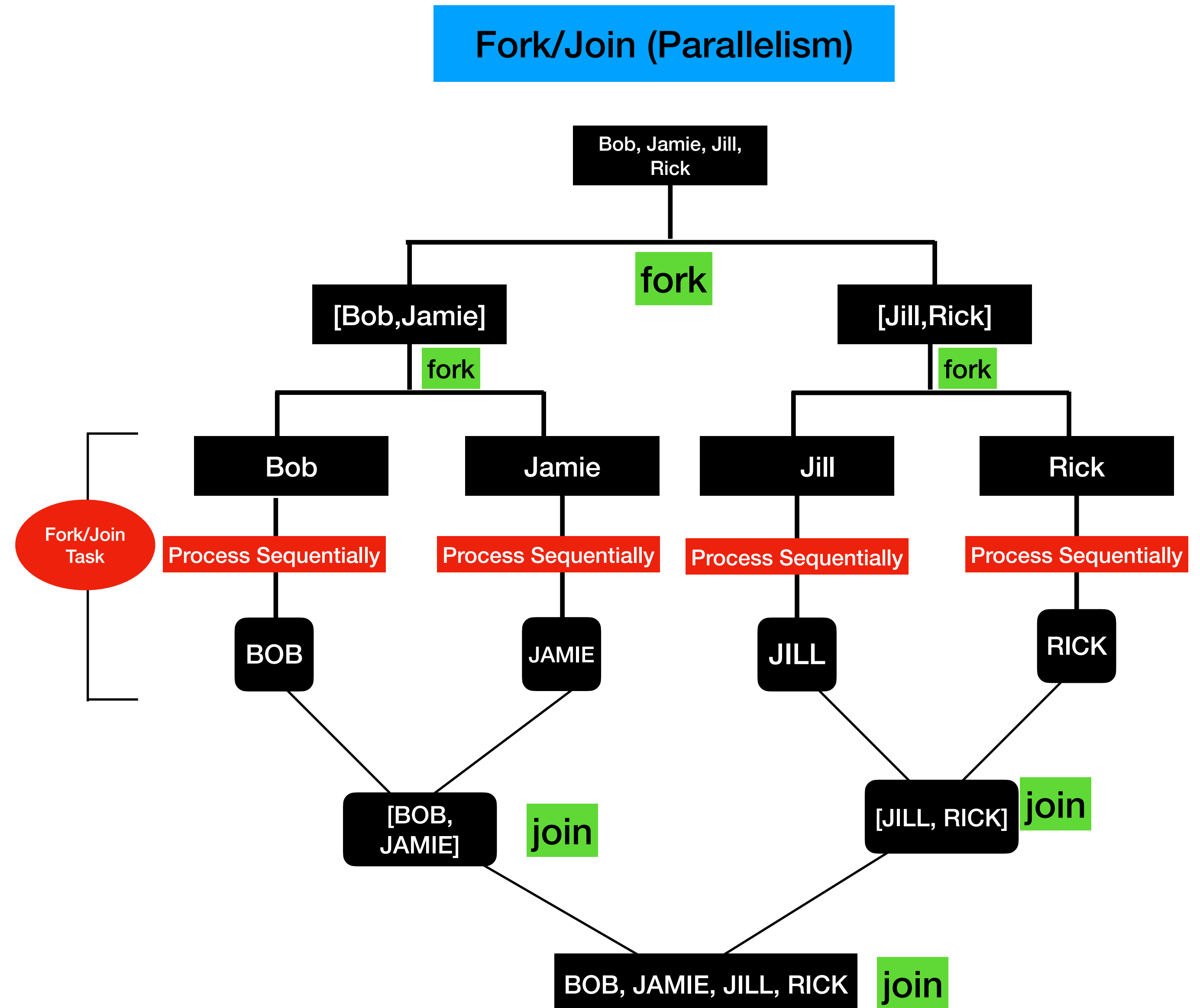
ForkJoin Pool to support Data Parallelism

ForkJoin Pool



ForkJoin Task

- ForkJoin Task represents part of the data and its computation
- Type of tasks to submit to ForkJoin Pool
- ForkJoinTask
 - RecursiveTask -> Task that returns a value
 - RecursiveAction -> Task that does not return a value



Fork/Join Example

ForkJoin - UseCase

Input

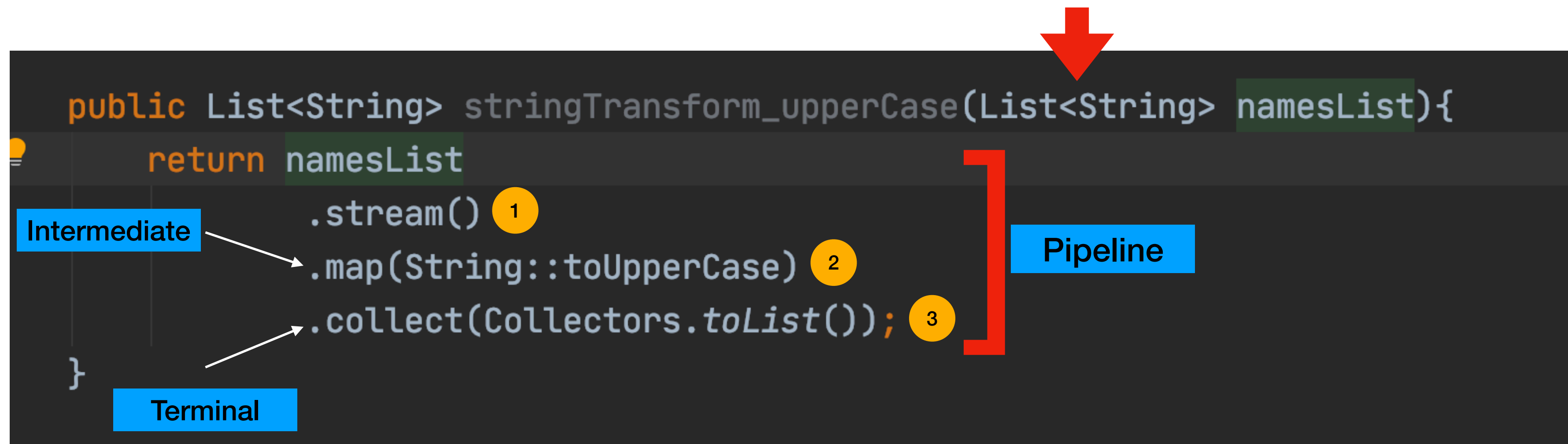
Output

[Bob, Jamie, Jill, Rick] -> [3 - Bob, 5 - Jamie, 4 - Jill, 4 - Rick]

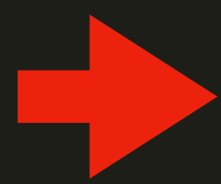
Streams API & Parallel Streams

Streams API

- Streams API got introduced in **Java 8**
- Streams API is used to process a collection of Objects
- Streams in Java are created by using the **stream()** method



Development > Programming Languages > Java



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Learn Lambdas, Streams , new Date APIs, Optionals and Parallel programming in Java 8 by coding it.

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- ✓

Learn Functional programming in Java
- ✓

Students will be able to implement the new Java 8 concepts in real time
- ✓

Learn the new Date/Time Libraries in Java 8
- ✓

Learn and understand Parallel Programming with the Streams.
- ✓

This course will be continuously updated.
- ✓

Complete understanding of Lambdas, Streams , Optional via code.
- ✓

Learn to build complex Streams Pipeline.
- ✓

Learn to use Method Reference , Constructor reference syntax.
- ✓

Student will be able to upgrade their Java knowledge with the new Functional Features.



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ParallelStreams


- This allows your code to run in parallel
- ParallelStreams are designed to solve **Data Parallelism**

```
public List<String> stringTransform_upperCase(List<String> namesList){  
    return namesList  
        .parallelStream() ←  
        .map(String::toUpperCase) ←  
        .collect(Collectors.toList());  
}
```


Watch “Concurrency vs Parallelism” & “Fork-Join Framework”

Stream/Parallel Stream

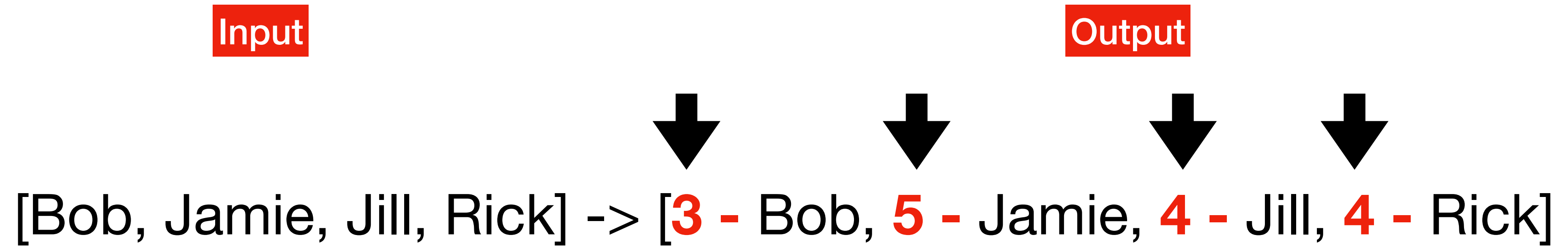
Stream

```
public List<String> stringTransform_upperCase(List<String> namesList){  
    return namesList  
        .stream()   
        .map(String::toUpperCase)  
        .collect(Collectors.toList());  
}
```

Parallel Stream

```
public List<String> stringTransform_upperCase(List<String> namesList){  
    return namesList  
        .parallelStream()   
        .map(String::toUpperCase)  
        .collect(Collectors.toList());  
}
```


Parallel Streams - UseCase



Unit Testing Parallel Streams Using JUnit5

Why Unit Tests ?

- Unit Testing allows you to programmatically test your code
- Manual Testing slows down the development and delivery
- Unit Testing allows the developer or the app team to make enhancements to the existing code easily and faster

Sequential/Parallel Functions in Streams API

sequential() and parallel()

- Streams API are **sequential** by default
 - sequential() -> Executes the stream in sequential
 - parallel() -> Executes the stream in parallel
- Both the functions() changes the behavior of the whole pipeline

sequential()




- Changing the **parallelStream()** behavior to sequential




```
public List<String> stringTransform(List<String> namesList){  
    return namesList  
        .parallelStream() ←  
        .map(this::transform)  
        .sequential() ←  
        .collect(Collectors.toList());  
}
```

Sequential

parallel()

- Changing the **stream()** behavior to parallel

```
public List<String> stringTransform(List<String> namesList){  
    return namesList  
        .stream()    
        .map(this::transform)  
        .parallel()   
        .collect(Collectors.toList());  
}
```

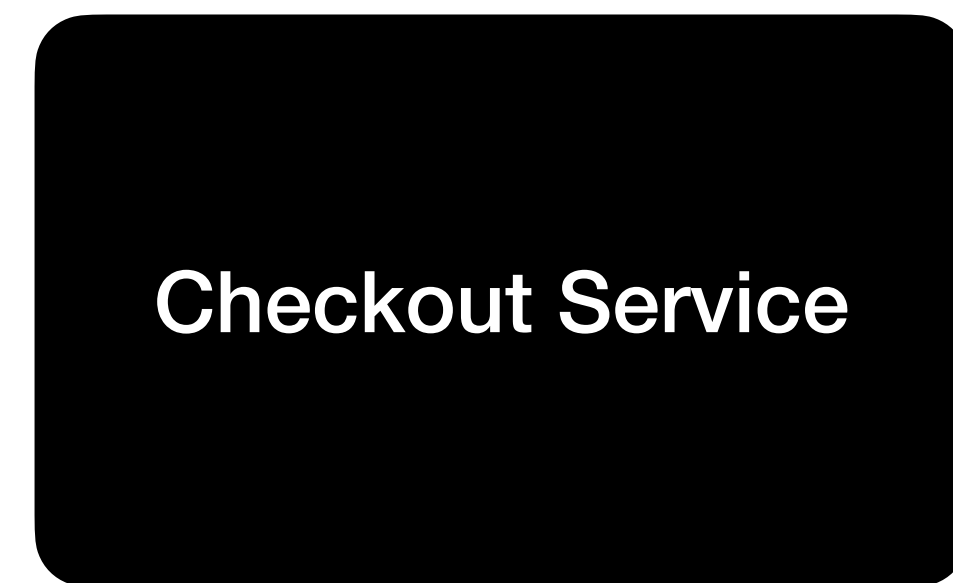


When to use `sequential()` and `parallel()` ?

Used these functions when I would like to evaluate between `sequential()` and `parallel()`

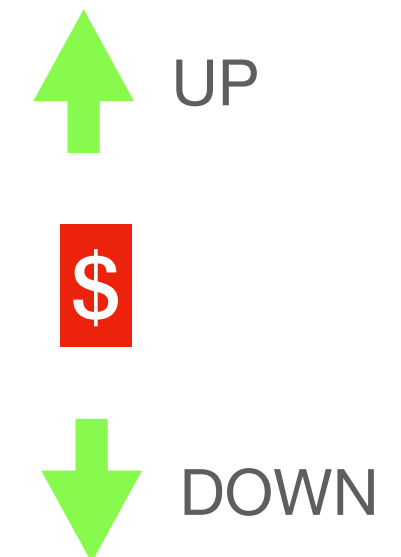
Overview of the Retail Checkout Service

Checkout Service(BackEnd)



CartItem

Price Validator
Service



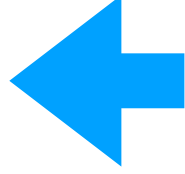
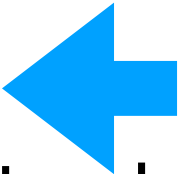
ParallelStreams

How it works ?

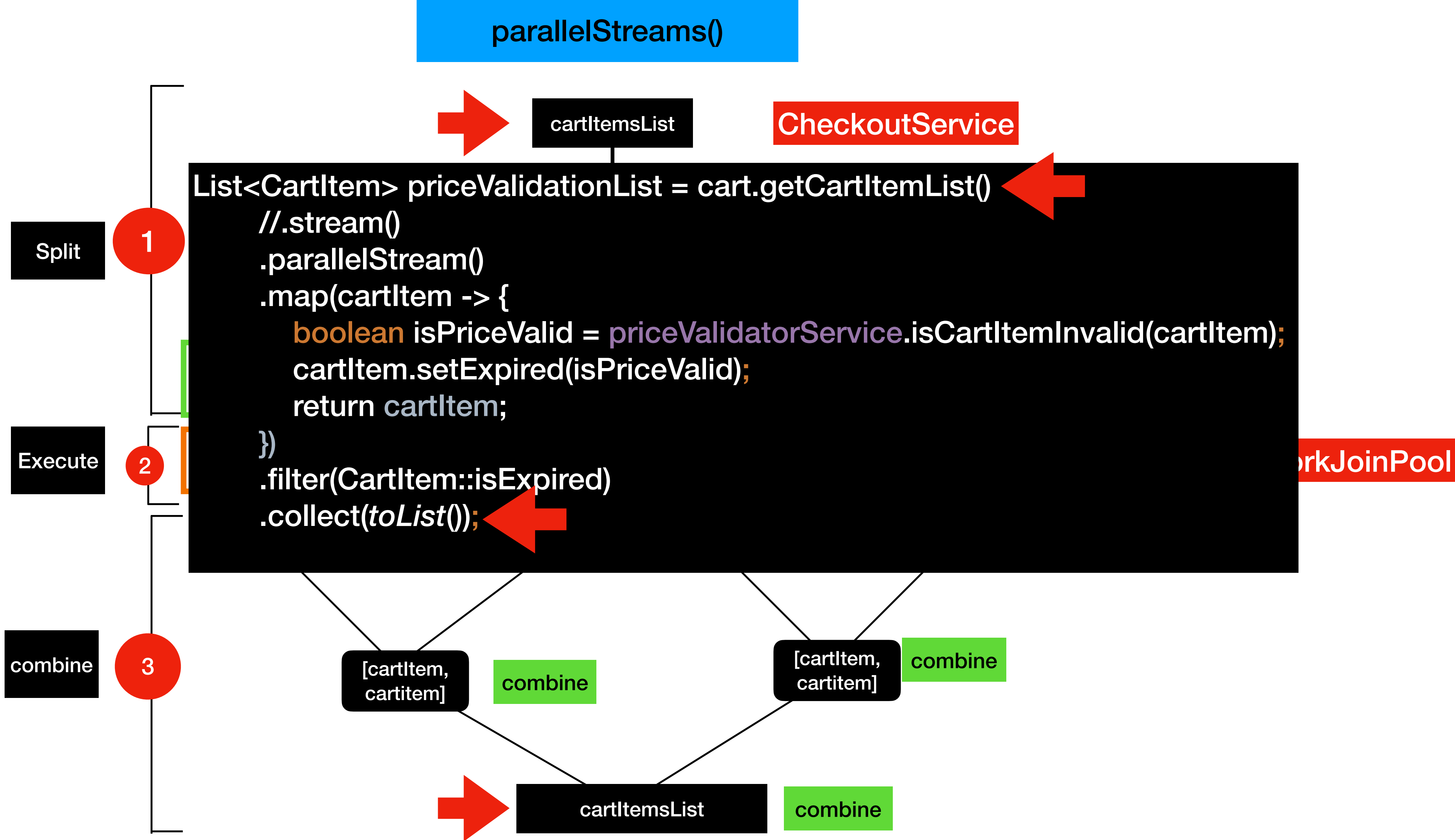
ParallelStreams - How it works ?

- `parallelStream()`
 - **Split** the data in to chunks
 - **Execute** the data chunks
 - **Combine** the result

parallelStream() - How it works ?

- **Split** 
 - Data Source is split in to small data chunks
 - Example - **List Collection** split into chunks of elements to **size 1**
 - This is done using **Spliterators**
 - For ArrayList, the **Spliterator** is **ArrayListSpliterator**
- **Execute** 
 - Data chunks are applied to the Stream Pipeline and the **Intermediate** operations executed in a **Common ForkJoin Pool**
 - Watch the **Fork/Join FrameWork** Lectures
- **Combine**
 - Combine the executed results into a final result
 - Combine phase in Streams API maps to **terminal** operations
 - Uses collect() and reduce() functions
 - **collect(toList())**

parallelStream() - How it works ?



Comparing **ArrayList** vs **LinkedList** ParallelStreams Performance

Splitter in ParallelStreams

- Data source is split in to multiple chunks by the Splitter
- Each and every collection has a different Splitter Implementation
- Performance differ based on the implementation

**Multiply each value in the
collection by a user passed value**

[1, 2, 3, 4] -> [2, 4, 6, 8]

Value * 2

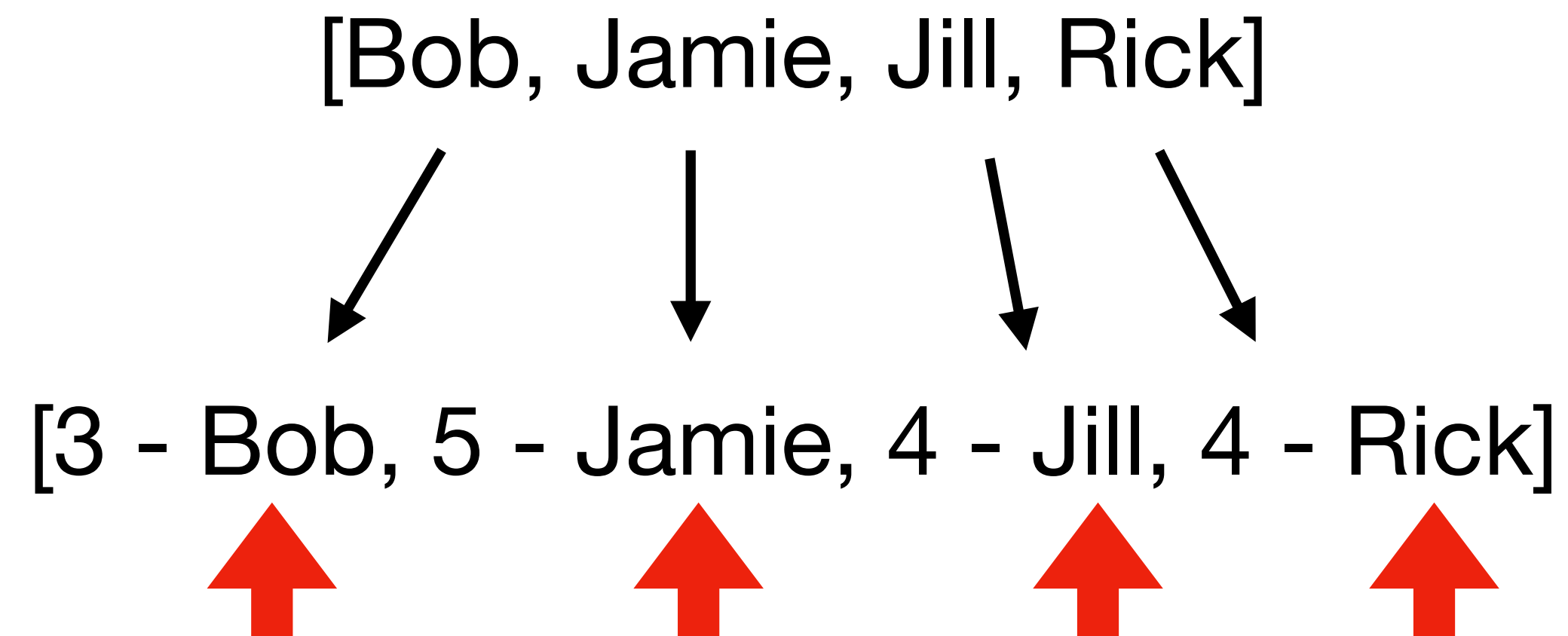
Summary - Splitter in ParallelStreams

- Invoking **parallelStream()** does not guarantee faster performance of your code
 - Need to perform additional steps compared to sequential
 - Splitting , Executing and Combining

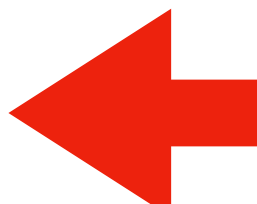
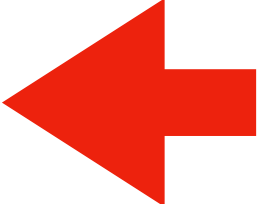
Recommendation - Always compare the performance before you use parallelStream()

Parallel Streams Final Computation Result Order

Parallel Streams - Final Computation Result Order



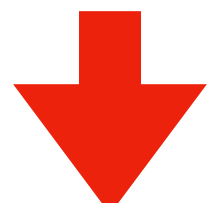
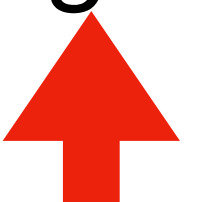
Parallel Streams - Final Computation Result Order

- The order of the collection depends on:
 - Type of Collection
 - Splitter Implementation of the collection
- Example : ArrayList
 - Type of Collection - **Ordered** 
 - Splitter Implementation - Ordered Splitter Implementation
- Example : Set
 - Type of Collection - **UnOrdered** 
 - Splitter Implementation - UnOrdered Splitter Implementation

**Collect
&
Reduce**

Collect() vs Reduce()

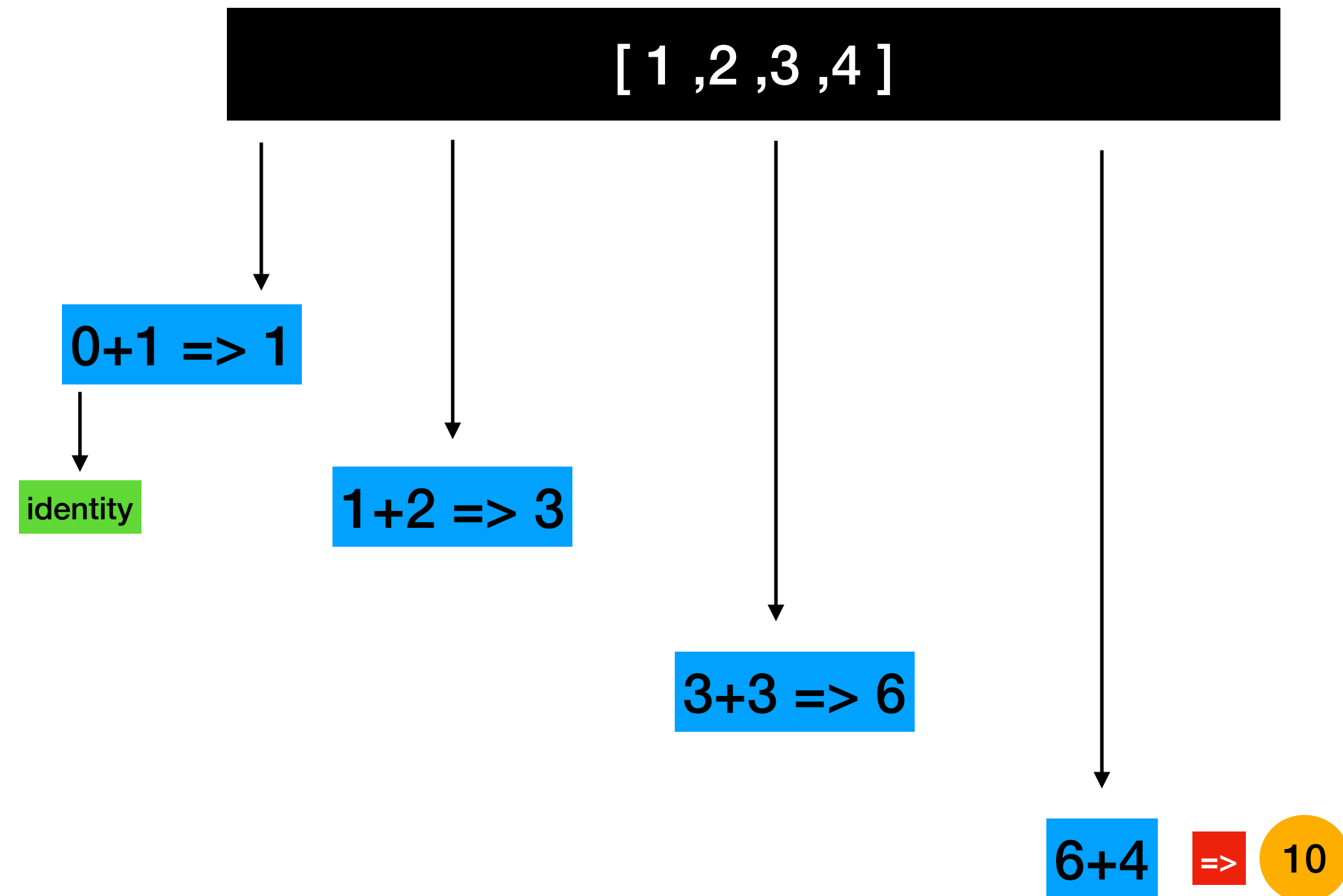
Collect

- Part of Streams API
- Used as a terminal operation in **Streams API**
- Produces a single result
- Result is produced in a mutable fashion
- Feature rich and used for many different use cases
- Example
 -  `collect(toList()), collect(toSet())`
 - `collect(summingDouble(Double::doubleValue);`

Reduce

- Part of Streams API
- Used as a terminal operation in **Streams API**
- Produces a single result
- Result is produced in a immutable fashion
- Reduce the computation into a single value
 - Sum, Multiplication
- Example
 - Sum -> `reduce(0.0, (x, y)->x+y)`
 - Multiply -> `reduce(1.0, (x, y)->x * y)`

How reduce() works ?



```
public static int reduce(){  
    int sum= List.of(1,2,3,4)  
                .stream()  
                .reduce( identity: 0, (x,y)->x+y);  
    return sum; 10  
}
```

Annotations in the code block: Red arrows point to `List.of(1,2,3,4)`, `.stream()`, and the lambda expression `(x,y)->x+y`. A green arrow points to the identity value `0`. The final result `10` is circled in yellow.

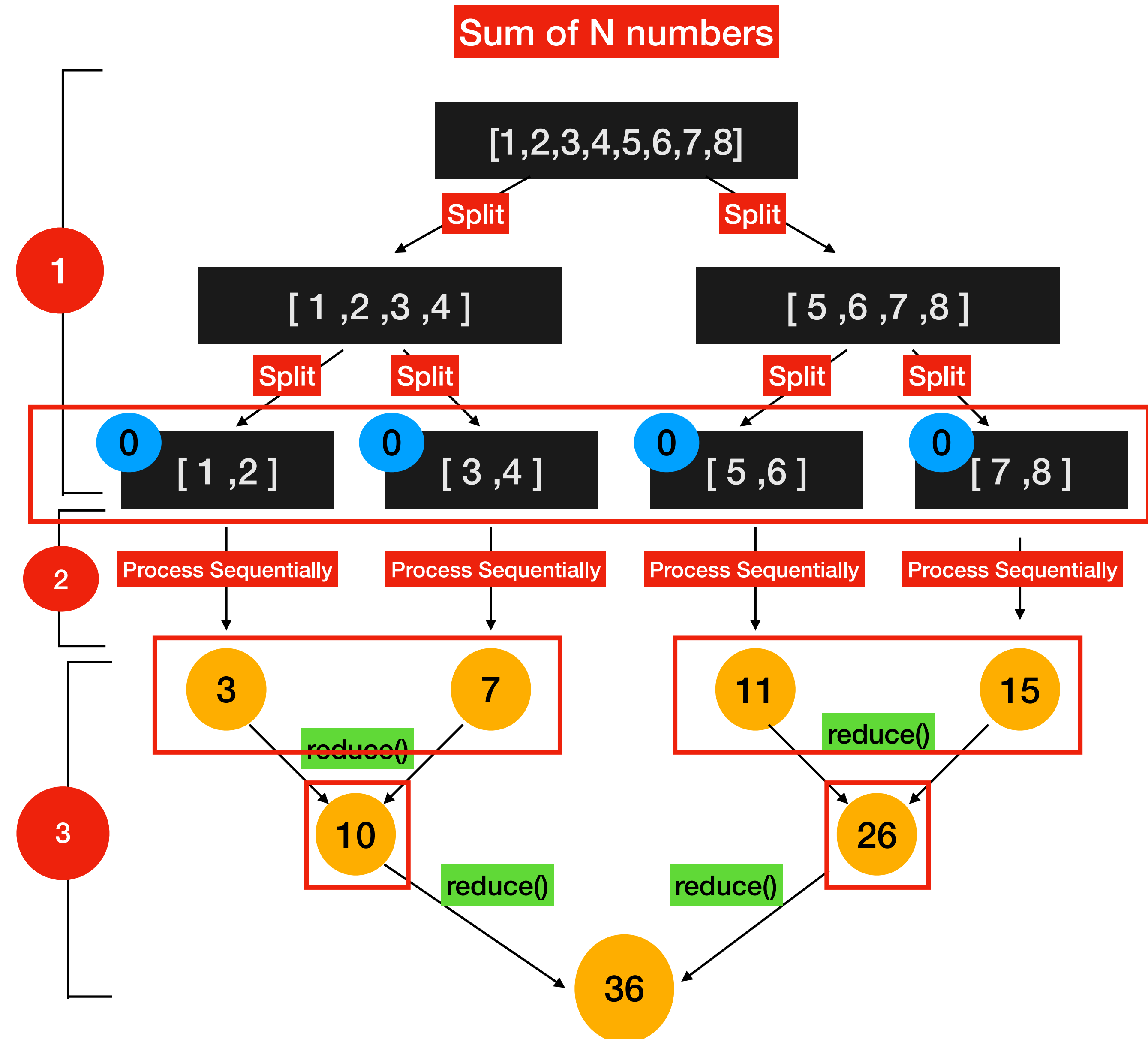
The `reduce()` function performs an immutable computation throughout in each and every step.

How reduce() with ParallelStream works ?


Sum of N numbers - reduce() and parallelStream()

```
public static int reduce_ParallelStream(){  
    int sum= List.of(1,2,3,4,5,6,7, 8)  
                .parallelStream()  
                .reduce( identity: 0, (x,y)->x+y);  
    return sum; 36  
}
```

- 1 Splitter
- 2 ForkJoinPool
- 3 Reduce



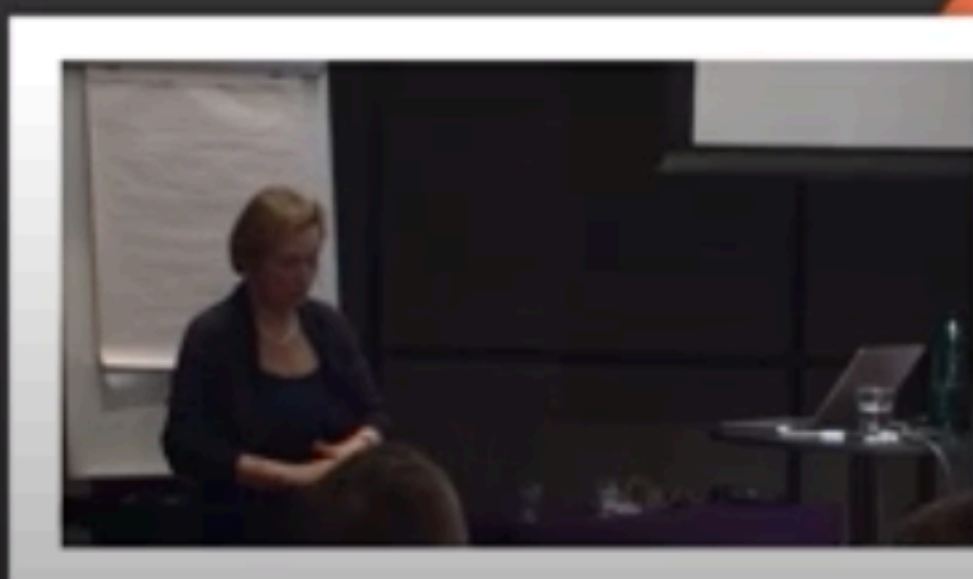
Want to learn more ?



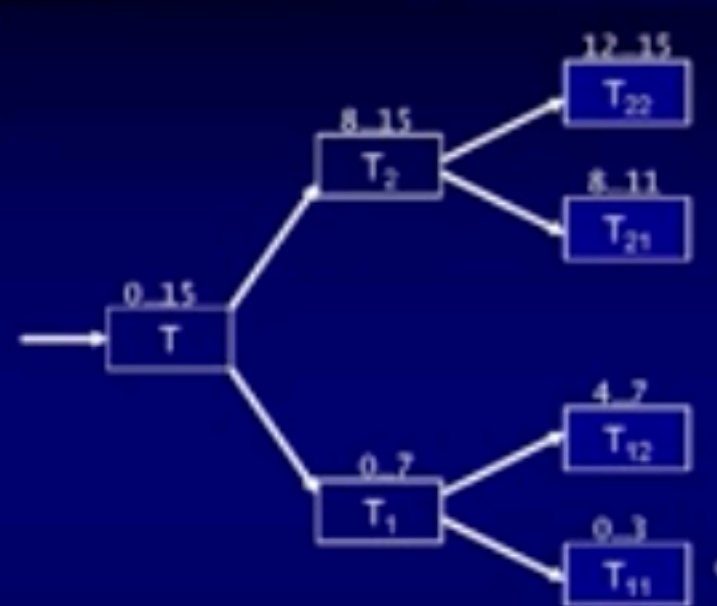
**STREAMS IN JAVA 8 (PART 01/02):
REDUCE VS COLLEC**

BREV. 1 / DAY 2 / 9 MARCH 2016 / 14:15-15:00

Angelika Langer, Angelika Langer Training & Consulting



parallel stream's reduce(), pt. 1: fork+execute



executes:

```
int sum11  
= streamChunk_0_3  
  .mapToInt(s -> s.length)  
  .reduce(0, (11,12) -> 11+12);
```

- each task feeds the initial value to the accumulator function !
 - initial value must be the identity

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http://www.angelikalanger.com/
last updated: 31/03/16, 15:00

reduce/collect (19)

19:08 / 44:57

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Streams in Java 8: Reduce vs. Collect

12,839 views • Apr 28, 2016

243 6 SHARE SAVE ...

Collect() & Reduce() Hands-On


Identity in reduce()

Identity in reduce()

- Identity gives you the same value when its used in the computation
- Addition: **Identity = 0**
 - $0 + 1 \Rightarrow 1$
 - $0 + 20 \Rightarrow 20$
- Multiplication : **Identity = 1**
 - $1 * 1 \Rightarrow 1$
 - $1 * 20 \Rightarrow 20$

Sum of N numbers - reduce() and parallelStream()

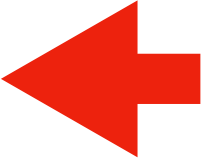
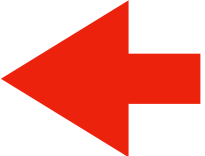
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                .parallelStream()  
                .reduce( identity: 0, (x,y)->x+y);  
    return sum;  
}
```



reduce() is recommended for computations that are associative

Parallel Stream Operations & Poor Performance

Parallel Stream Operations & Poor Performance

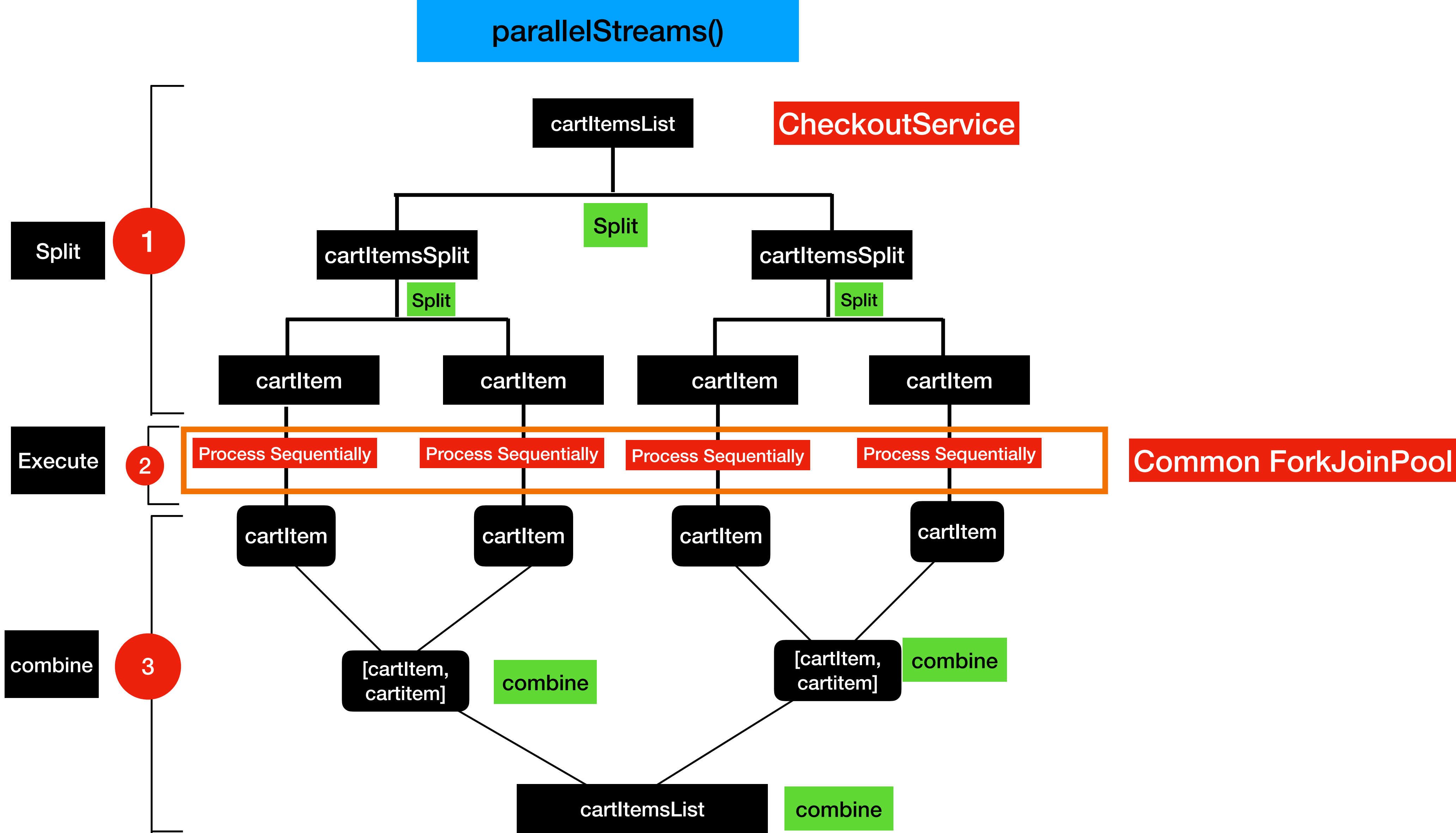
- Stream Operations that perform poor
- Impact of **Boxing** and **UnBoxing** when it comes to parallel Streams
 - **Boxing** -> Converting a Primitive Type to Wrapper class equivalent
 - **1 -> new Integer(1)** 
 - **UnBoxing** -> Converting a Wrapper class to Primitive equivalent
 - **new Integer(1) -> 1** 

Common ForkJoin Pool

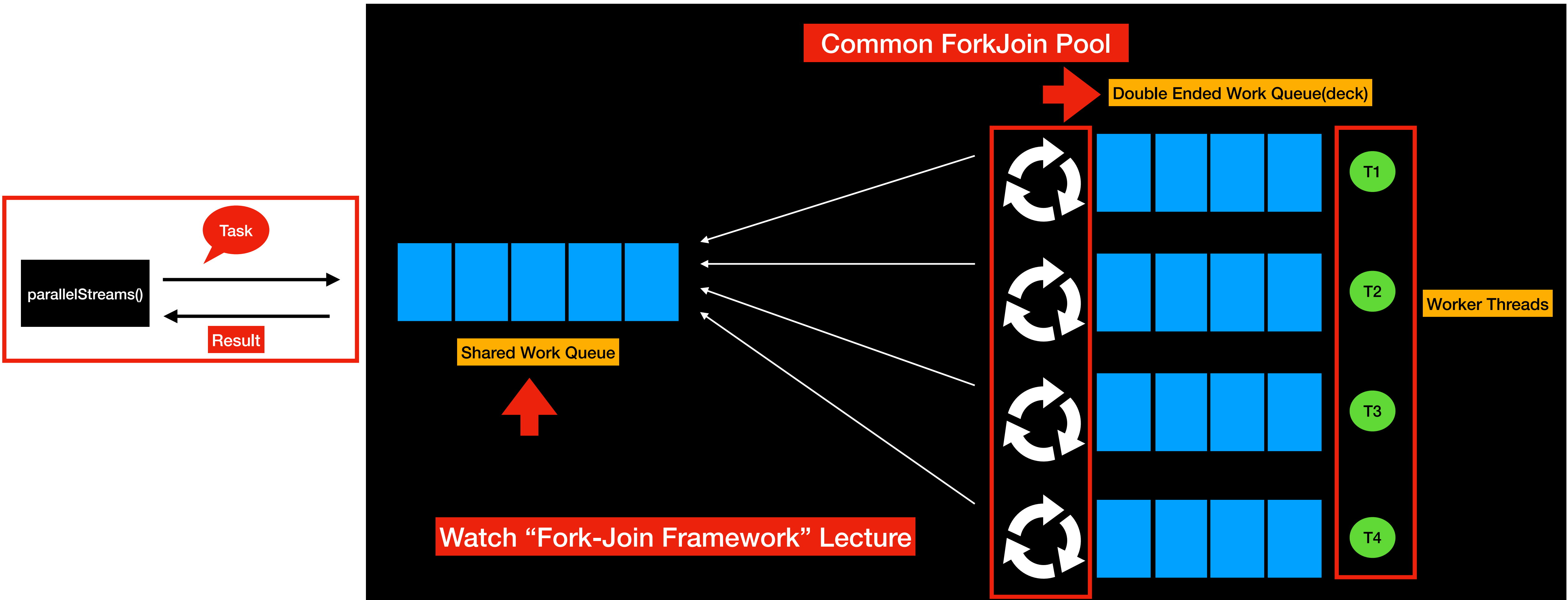
Common ForkJoin Pool

Execution Engine for Parallel Streams

parallelStream() - How it works ?



Common ForkJoin Pool



Common ForkJoin Pool

- Common ForkJoin Pool is used by:
 - ParallelStreams
 - CompletableFuture
 - Completable Future have options to use a User-defined ThreadPools
- Common ForkJoin Pool is shared by the whole process

Parallelism & Threads in Common ForkJoinPool

Parallelism & Threads in Common ForkJoinPool

- `parallelStreams()`
 - Runs your code in parallel
 - Improves the performance of the code
- Is there a way to look in to parallelism and threads involved ?
 - **Yes**

Modifying Default parallelism in Parallel Streams

Modifying Default parallelism

➡ `System.setProperty("java.util.concurrent.ForkJoinPool.common.parallelism", "100");`

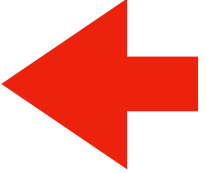
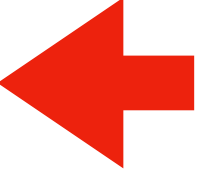
OR

➡ `-Djava.util.concurrent.ForkJoinPool.common.parallelism=100`

Parallel Streams - Summary

Parallel Streams - When to use them ?

Parallel Streams - When to use them ?

- Parallel Streams do a lot compared to sequential(default) Streams
- Parallel Streams
 - Split 
 - Execute
 - Combine 

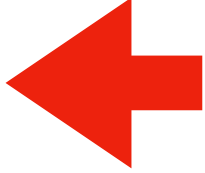
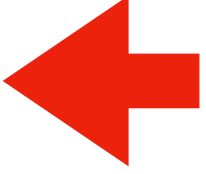
Parallel Streams - When to use them ?

- Computation takes a longer time to complete
- Lots of data
- More cores in your machine

Always compare the performance between sequential and parallel streams

Parallel Streams - When to use them ?

Parallel Streams - When not to use them ?

- Parallel Streams
 - Split 
 - Execute
 - Combine 
- Data set is small
- Auto Boxing and Unboxing doesn't perform better
- Stream API operators -> **iterate()**, **limit()**

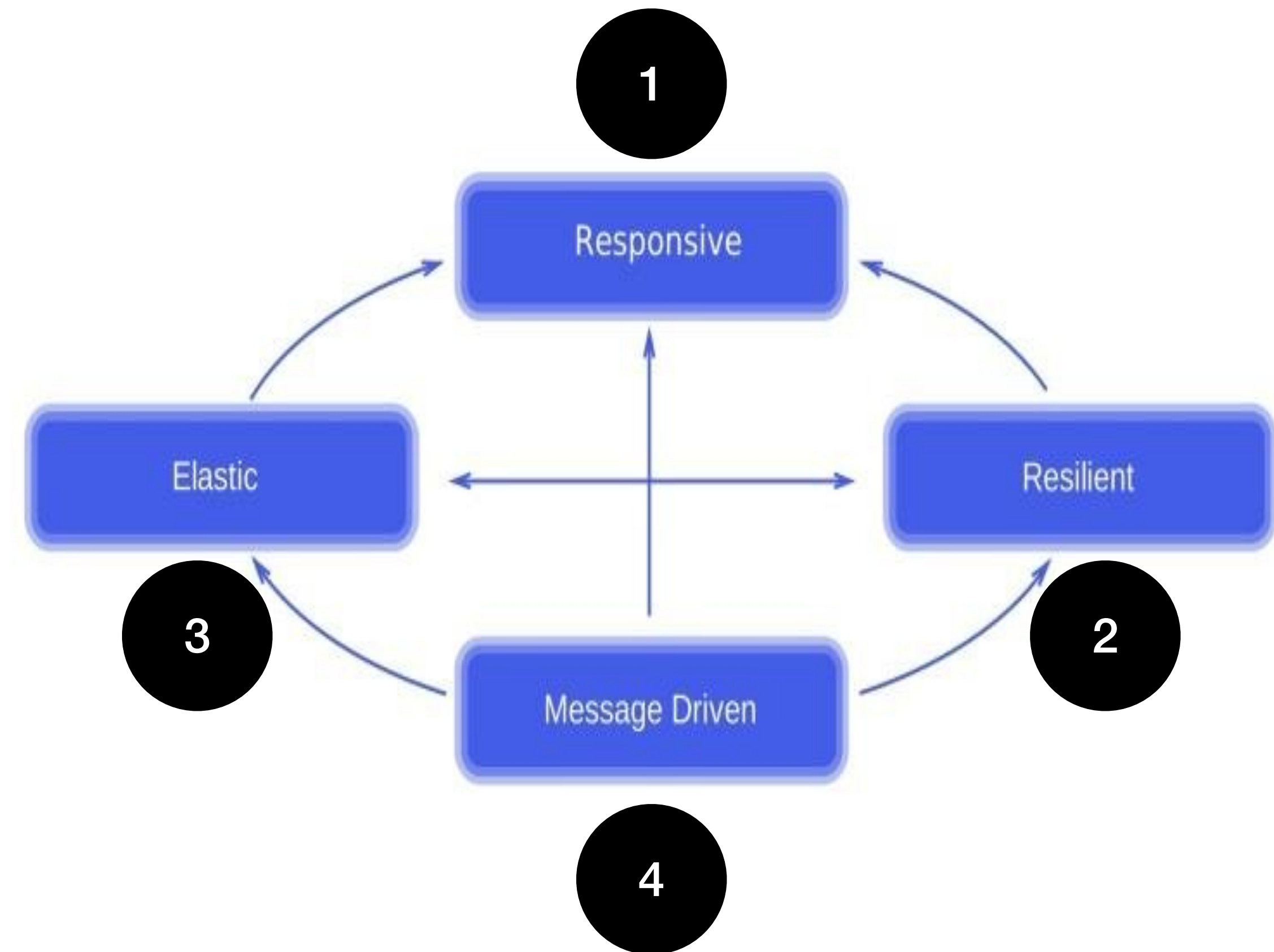
CompletableFuture

CompletableFuture


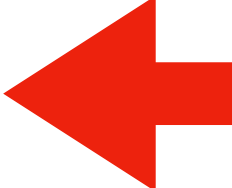
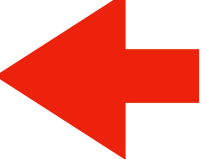
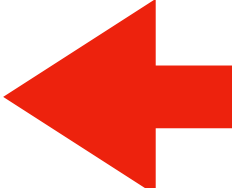
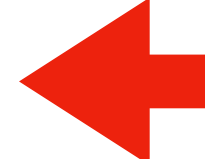
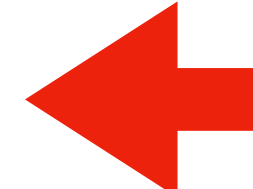
- Introduced in **Java 8**
- CompletableFuture is an **Asynchronous Reactive Functional Programming API**
- Asynchronous Computations in a functional Style
- CompletableFuture API is created to solve the limitations of Future API

CompletableFuture and Reactive Programming

- **Responsive:**
 - Fundamentally Asynchronous
 - Call returns immediately and the response will be sent when its available
- **Resilient:**
 - Exception or error won't crash the app or code
- **Elastic:**
 - Asynchronous Computations normally run in a pool of threads
 - No of threads can go up or down based on the need
- **Message Driven:**
 - Asynchronous computations interact with each through messages in a event-driven style



CompletableFuture API

- **Factory Methods** 
 - Initiate asynchronous computation 
- **Completion Stage Methods** 
 - Chain asynchronous computation 
- **Exception Methods** 
 - Handle Exceptions in an Asynchronous Computation 

**Lets Write
our
First CompletableFuture**

CompletableFuture

supplyAsync()

- FactoryMethod
- Initiate Asynchronous computation
- Input is **Supplier** Functional Interface
- Returns CompletableFuture<**T**>()

thenAccept()

- CompletionStage Method
- Chain Asynchronous Computation
- Input is **Consumer** Functional Interface
 - Consumes the result of the previous
- Returns CompletableFuture<**Void**>
- Use it at the end of the Asynchronous computation

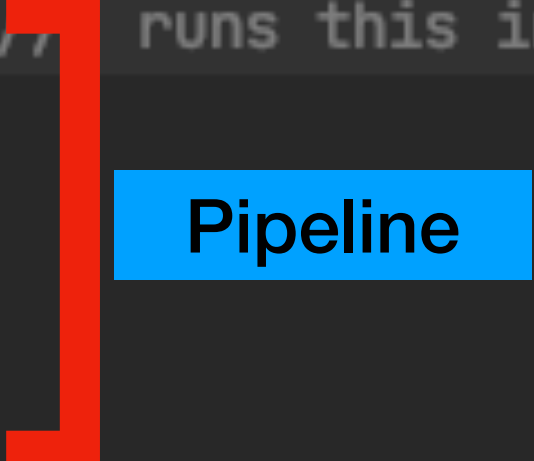
thenApply()

thenApply()

- Completion Stage method
- Transform the data from one form to another
- Input is **Function** Functional Interface
- Returns CompletableFuture<**T**>

CompletableFuture

```
    HelloWorldService helloWorldService = new HelloWorldService();  
1  CompletableFuture.supplyAsync(() -> helloWorldService.helloWorld()) // runs this in a common fork-join pool  
    2  .thenApply(String::toUpperCase)  
    3  .thenAccept((result) -> {  
        log("result " + result);  
    })  
    .join();  
  
    log("Done!");  
    delay(delayMilliseconds: 2000);  
}
```



Pipeline

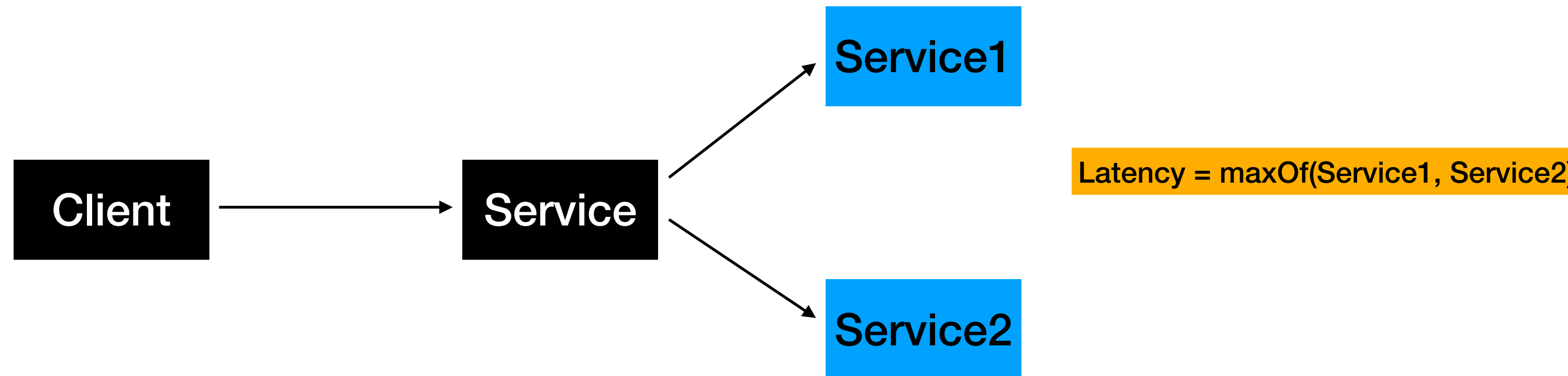
Unit Testing

CompletableFuture

**Combining independent
Async Tasks
using
“thenCombine”**

thenCombine()

- This is a Completion Stage Method
- Used to Combine Independent Completable Futures



- Takes two arguments
 - CompletionStage , BiFunction
- Returns a CompletableFuture

thenCompose

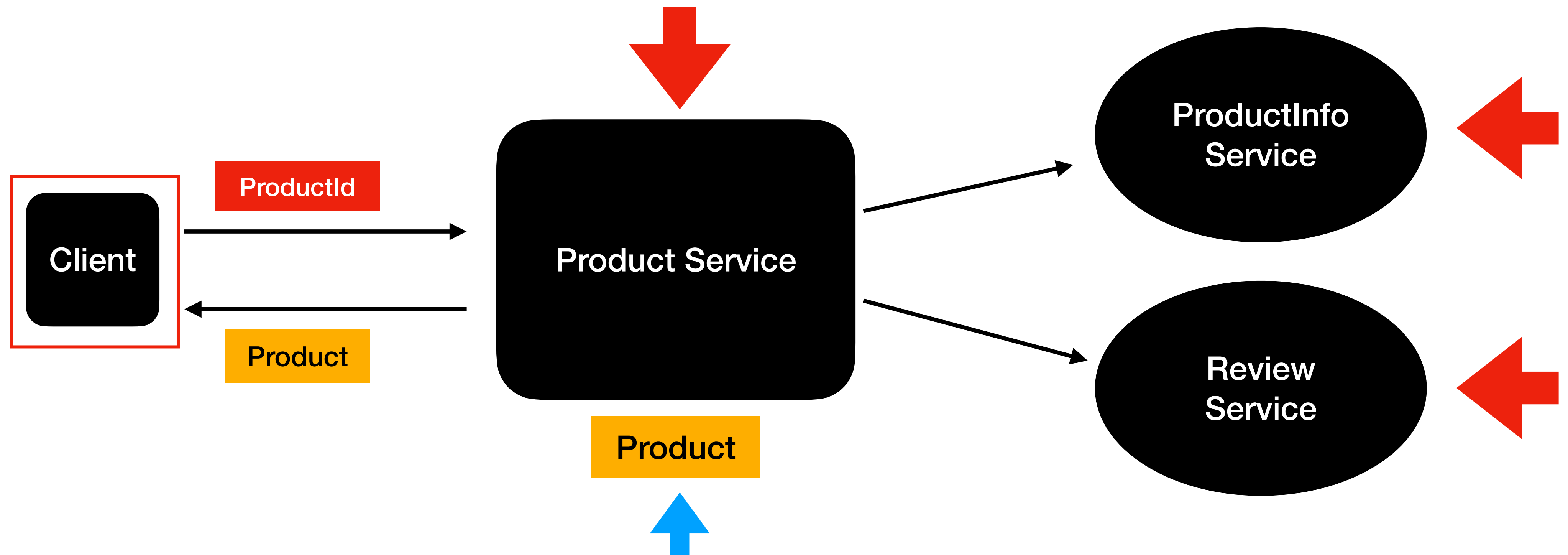
thenCompose()

- Completion Stage method
- Transform the data from one form to another
- Input is **Function** Functional Interface
- Deals with functions that return CompletableFuture
 - thenApply deals with Function that returns a value
- Returns CompletableFuture<**T**>



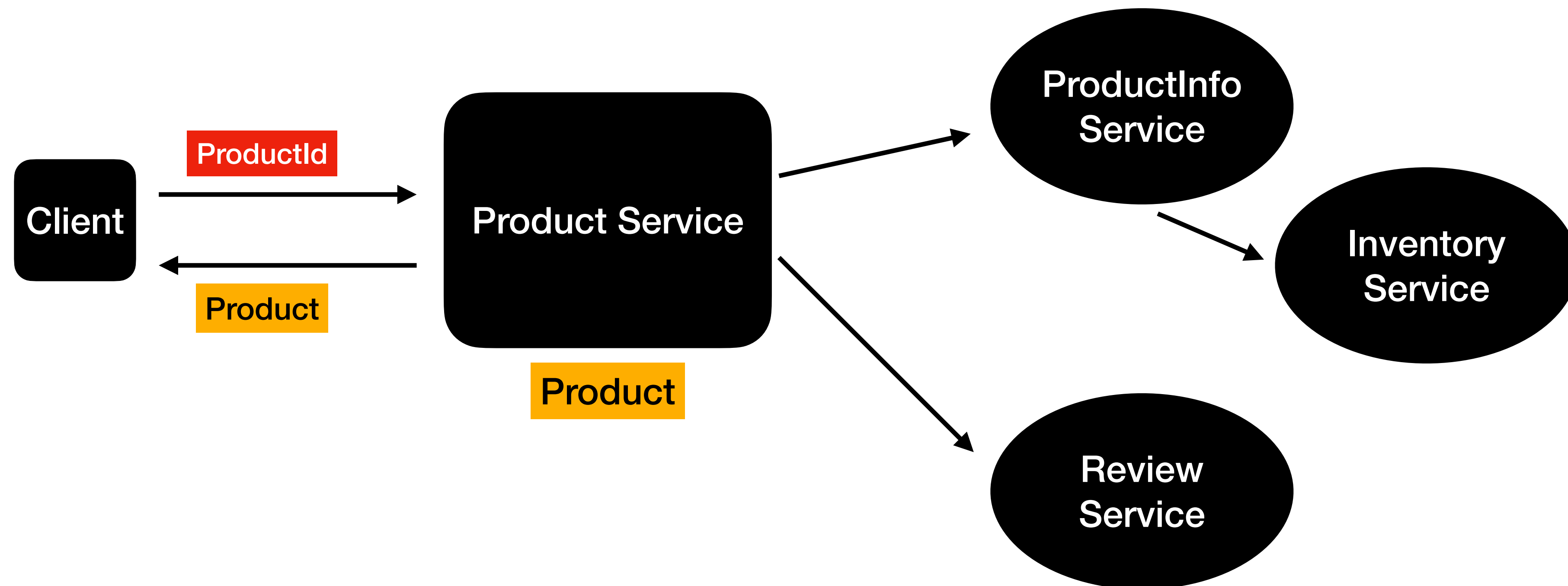
```
public CompletableFuture<String> worldFuture(String input)
{
    return CompletableFuture.supplyAsync(()->{
        delay(1000);
        return input+" world!";
    });
}
```

Product Service



Combining Streams & CompletableFuture

Product Service with Inventory



Exception Handling In CompletableFuture

Exception Handling in Java

- Exception Handling in Java is available since the inception of **Java**

```
public void exceptionHandling() {  
    → try {  
        // Code Statements  
        // Code Statements  
        // Code Statements ]  
    } catch (Exception e) {  
        // Handle the Exception ←  
    }  
}
```

Exception Handling in CompletableFuture

- CompletableFuture is a functional style API

```
public String helloWorld_3_async_calls() {  
    ➡ CompletableFuture<String> hello = CompletableFuture.supplyAsync(() -> this.hws.hello());  
    ➡ CompletableFuture<String> world = CompletableFuture.supplyAsync(() -> this.hws.world());  
    ➡ CompletableFuture<String> hiCompletableFuture = CompletableFuture.supplyAsync(() -> {  
        delay( delayMilliseconds: 1000);  
        return " HI CompletableFuture!";  
    });  
  
    String hw = hello  
        .thenCombine(world, (h, w) -> h + w) // (first,second)  
        .thenCombine(hiCompletableFuture, (previous, current) -> previous + current)  
        .thenApply(String::toUpperCase)  
        .join();  
    return hw;  
}
```

Exception Handling in CompletableFuture

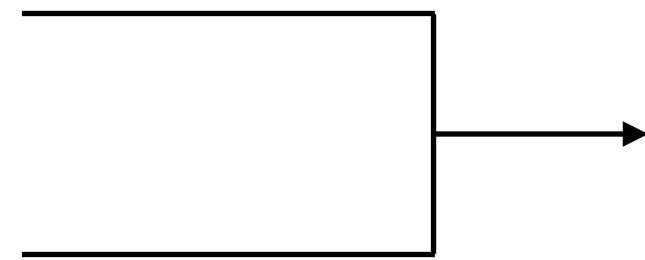
try/catch

```
public String helloWorld_3_async_calls1() {  
    try{  
        CompletableFuture<String> hello = CompletableFuture.supplyAsync(() -> this.hws.hello());  
        CompletableFuture<String> world = CompletableFuture.supplyAsync(() -> this.hws.world());  
        CompletableFuture<String> hiCompletableFuture = CompletableFuture.supplyAsync(() -> {  
            delay(delayMilliseconds: 1000);  
            return " HI CompletableFuture!";  
        });  
  
        String hw = hello  
            .thenCombine(world, (h, w) -> h + w) // (first,second)  
            .thenCombine(hiCompletableFuture, (previous, current) -> previous + current)  
            .thenApply(String::toUpperCase)  
            .join();  
  
        return hw;  
    } catch (Exception e){  
        log("Exception is " + e);  
        throw e;  
    }  
}
```

Exception Handling in CompletableFuture

- CompletableFuture API has functional style of handling exceptions
- Three options available:

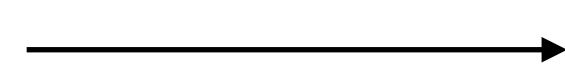
- `handle()`



Catch Exception and Recover

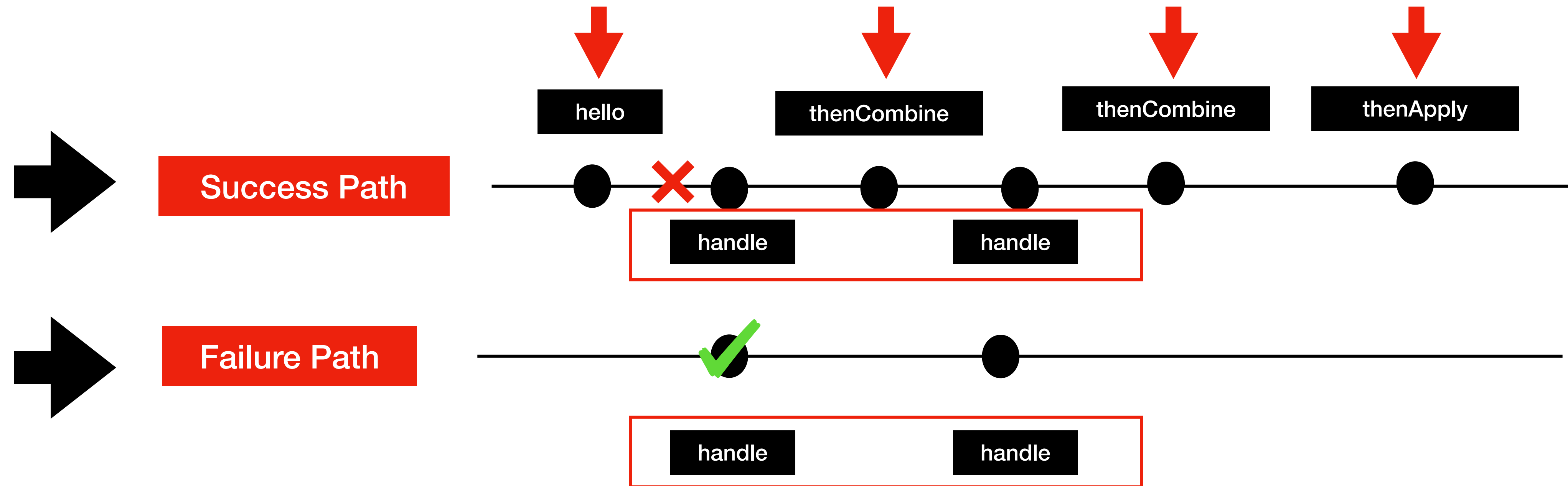
- `exceptionally()`

- `whenComplete()`

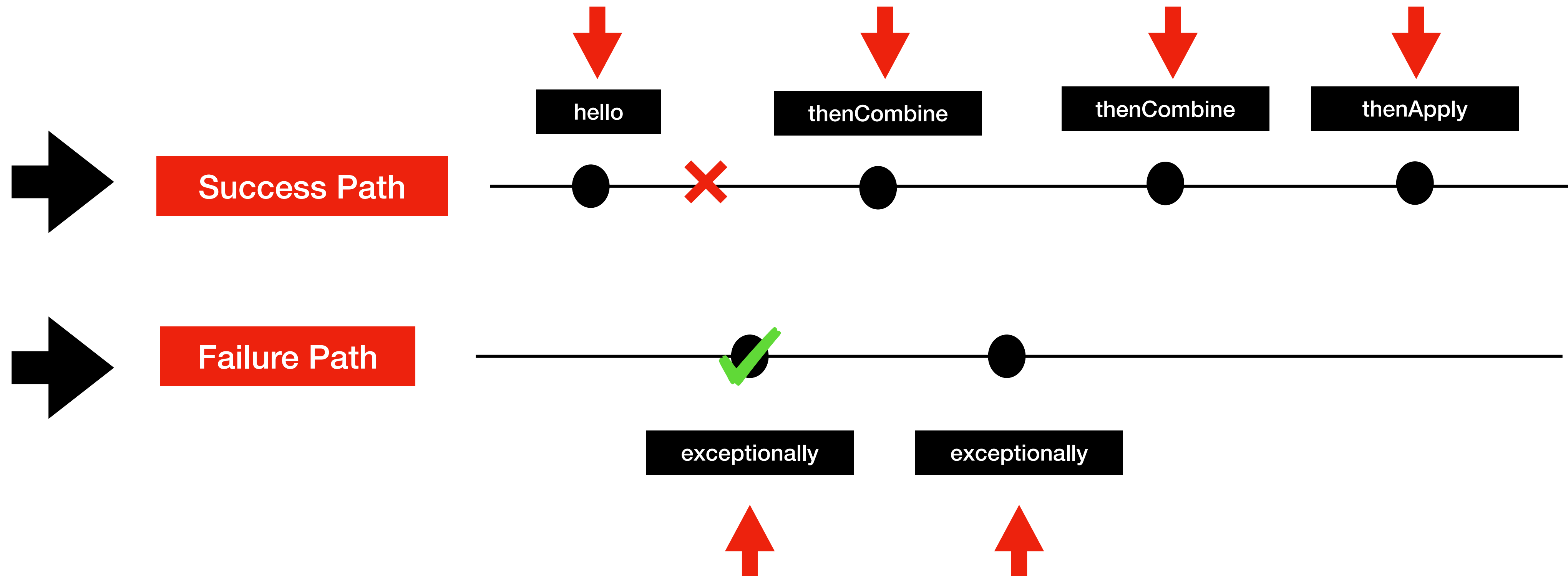


Catch Exception and Does not Recover

Exception Handling using handle()



Exception Handling using `exceptionally()`

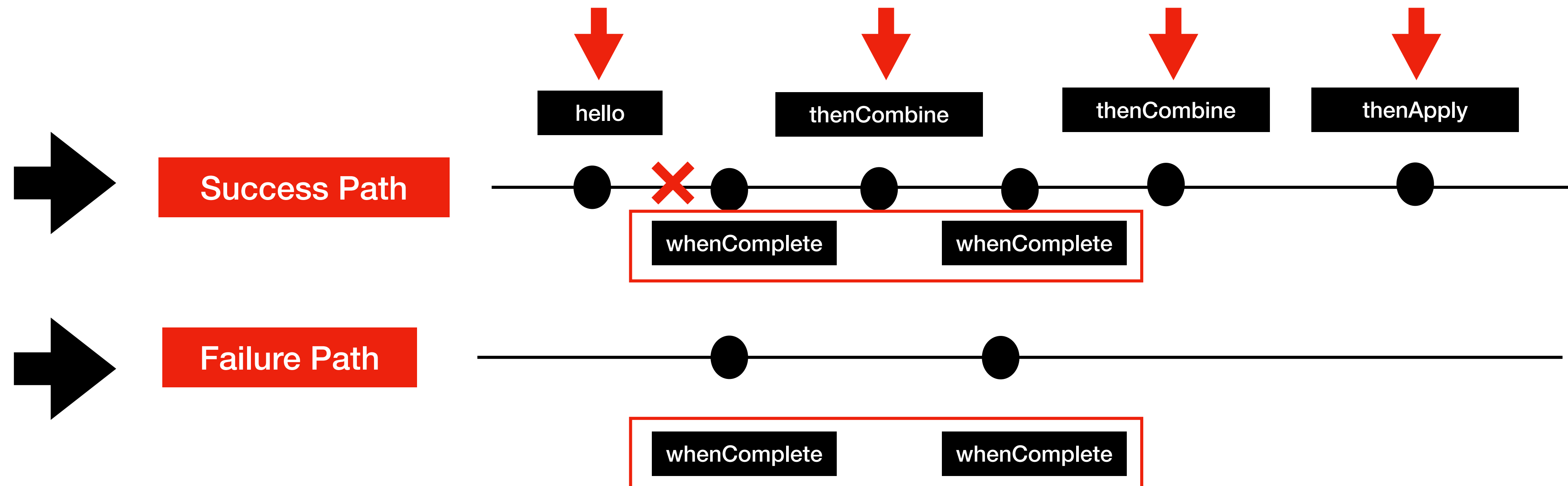


whenHandle()

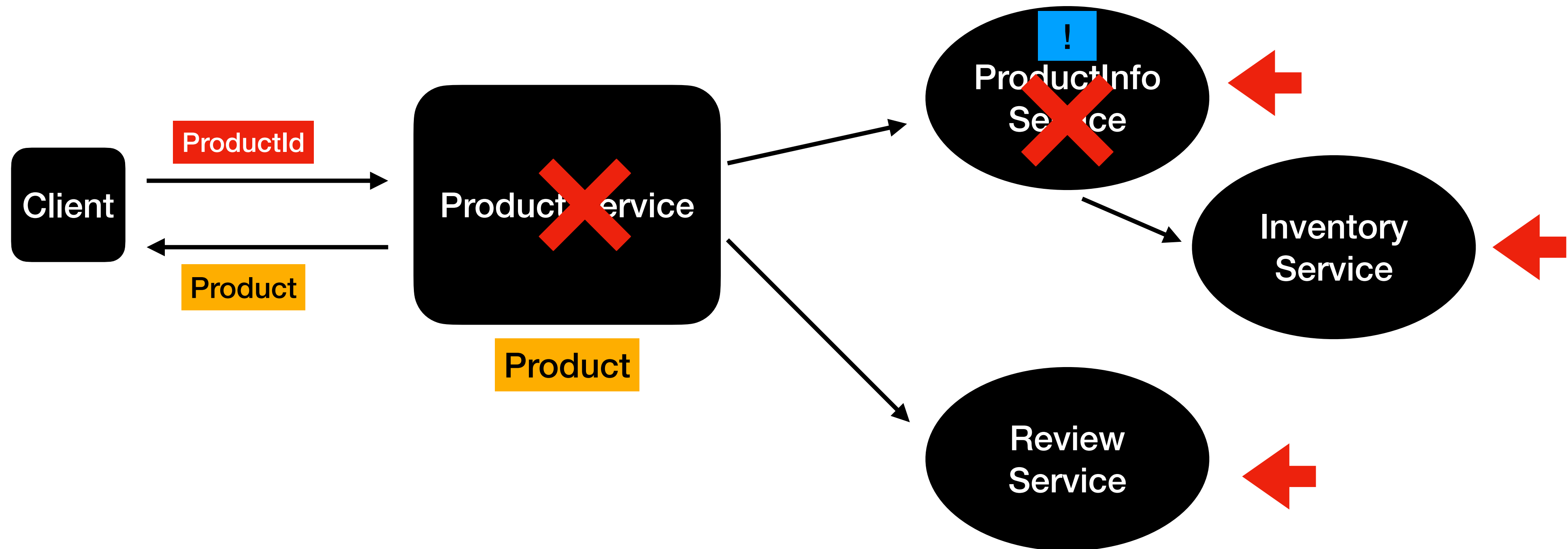
whenHandle()

- Exception handler in CompletableFuture API
- Catches the Exception but does not recover from the exception

Exception Handling using whenComplete()



Product Service with Inventory

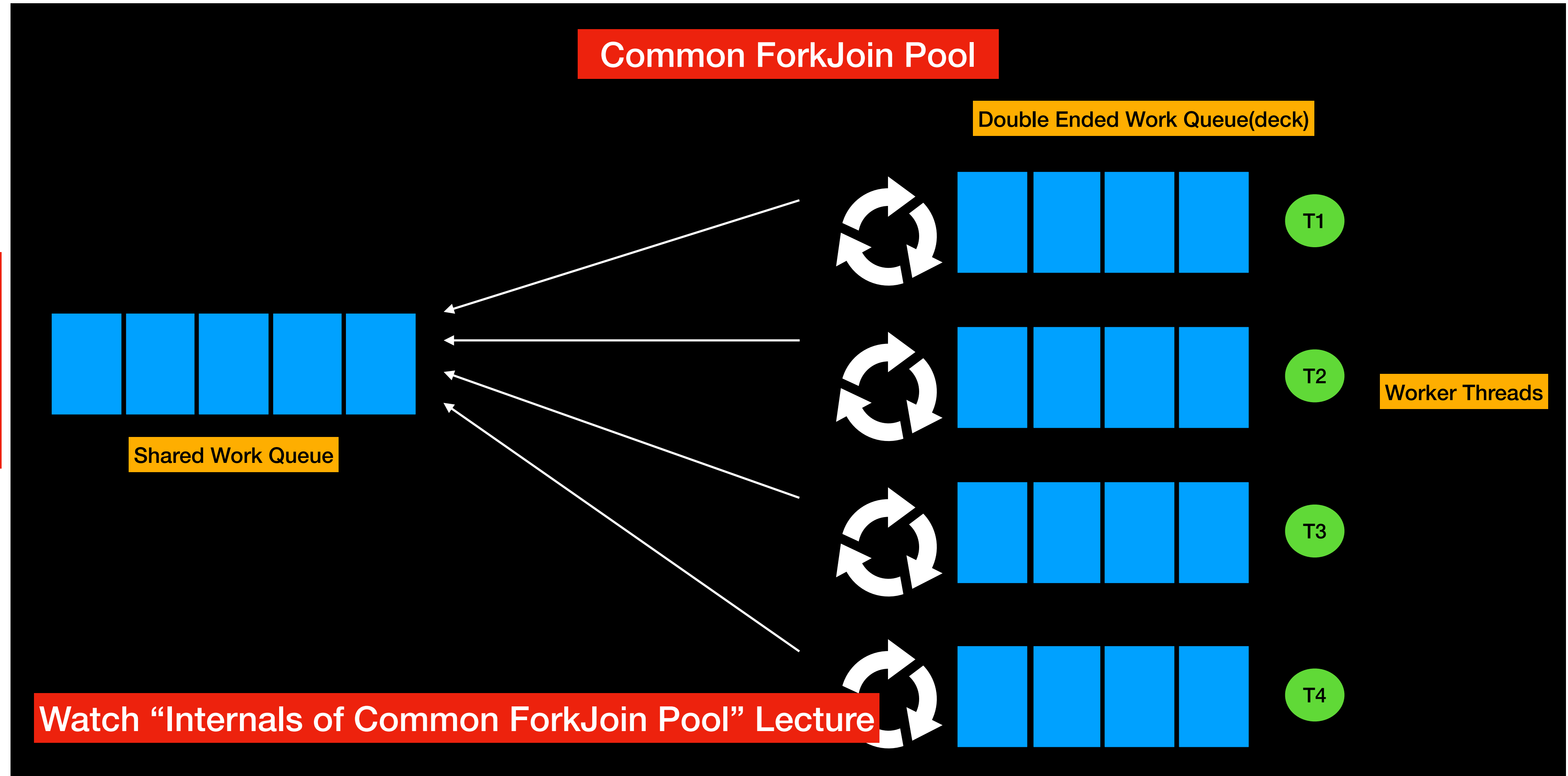
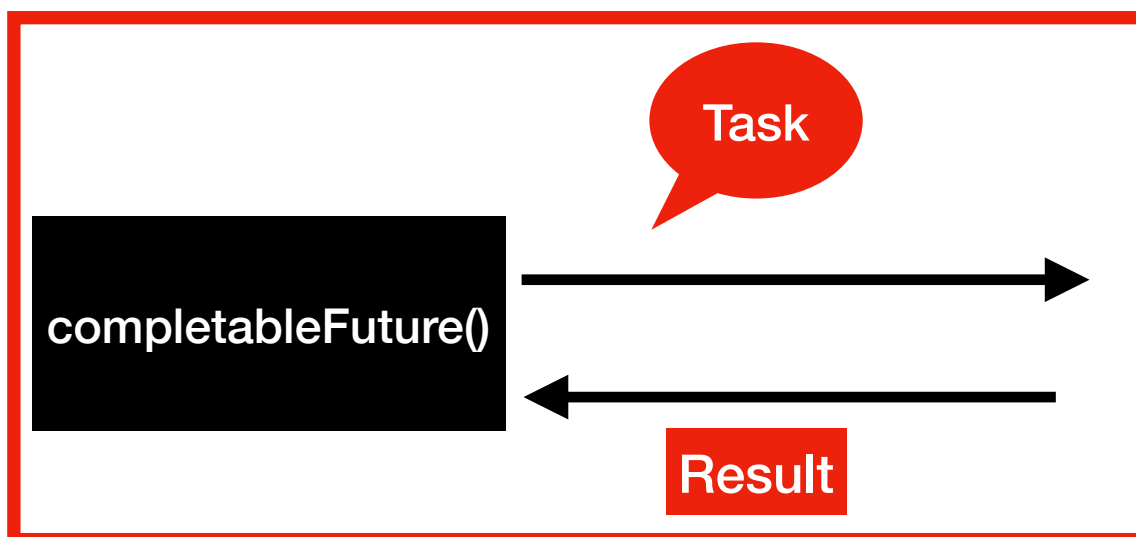


**CompletableFuture
Default ThreadPool**

CompletableFuture - ThreadPool

- By default, CompletableFuture uses the **Common ForkJoinPool**
 - The no of threads in the pool == number of cores

Common ForkJoin Pool



CompletableFuture & User Defined ThreadPool using ExecutorService

Why use a different ThreadPool ?

- Common ForkJoinPool is shared by
 - ParallelStreams
 - CompletableFuture
- Its common for applications to use **ParallelStreams** and **CompletableFuture** together
- The following issues may occur:
 - Thread being blocked by a time consuming task
 - Thread not available

Creating a User-Defined ThreadPool

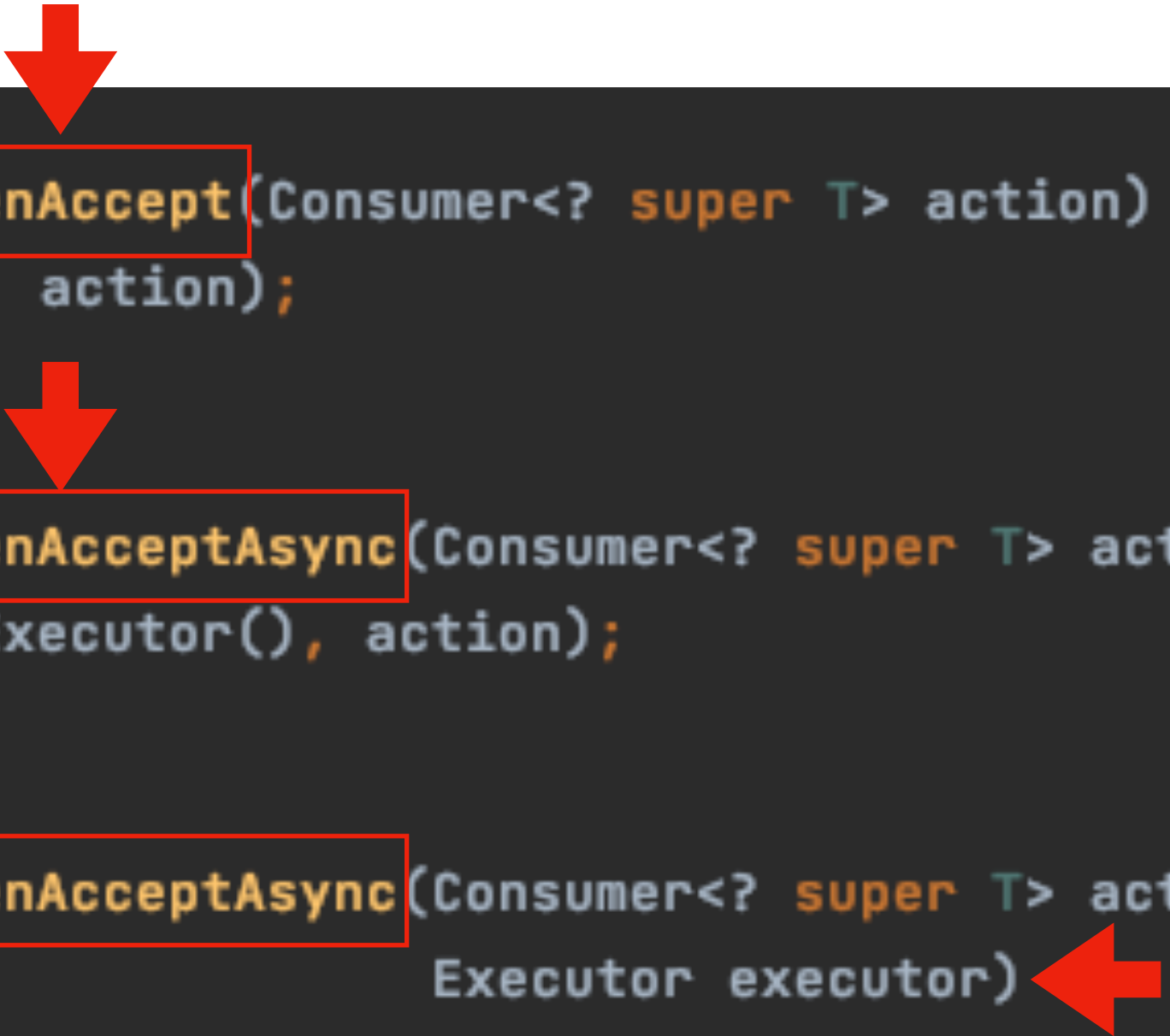
```
Executors.newFixedThreadPool(Runtime.getRuntime().availableProcessors());
```


Threads In CompletableFuture

Async() Overloaded Functions In CompletableFuture

Async Overloaded Functions

- thenAccept()



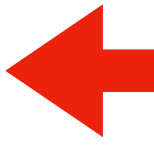

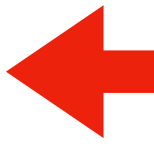
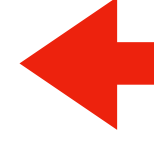
```
public CompletableFuture<Void> thenAccept(Consumer<? super T> action) {  
    return uniAcceptStage(e: null, action);  
}  
  
public CompletableFuture<Void> thenAcceptAsync(Consumer<? super T> action) {  
    return uniAcceptStage(defaultExecutor(), action);  
}  
  
public CompletableFuture<Void> thenAcceptAsync(Consumer<? super T> action,  
                                              Executor executor)  
    return uniAcceptStage(screenExecutor(executor), action);  
}
```

Async() Overloaded Functions

Regular Functions

- thenCombine()
- thenApply()
- thenCompose()
- thenAccept()

Async() overloaded Functions

- thenCombineAsync() 
- thenApplyAsync() 
- thenComposeAsync() 
- thenAcceptAsync() 

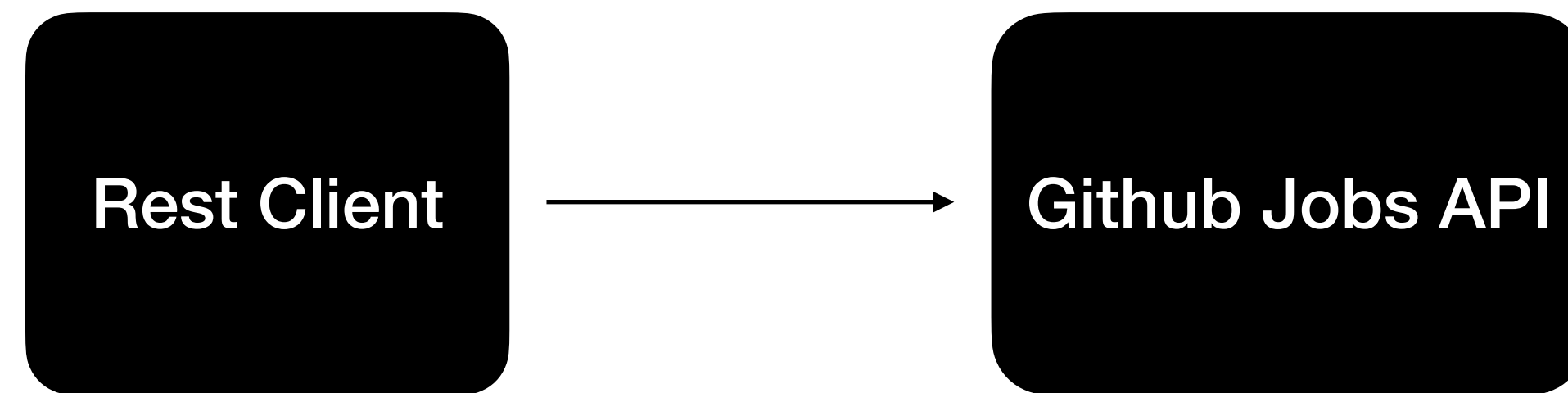
Async() Overloaded Functions

- Using `async()` functions allows you to change the thread of execution
- Use this when you have blocking operations in your `CompletableFuture` pipeline

Introduction to Spring WebClient and

Overview of the GitHub Jobs API

About this section



Build Restful API Using Spring WebClient

Why Spring WebClient?

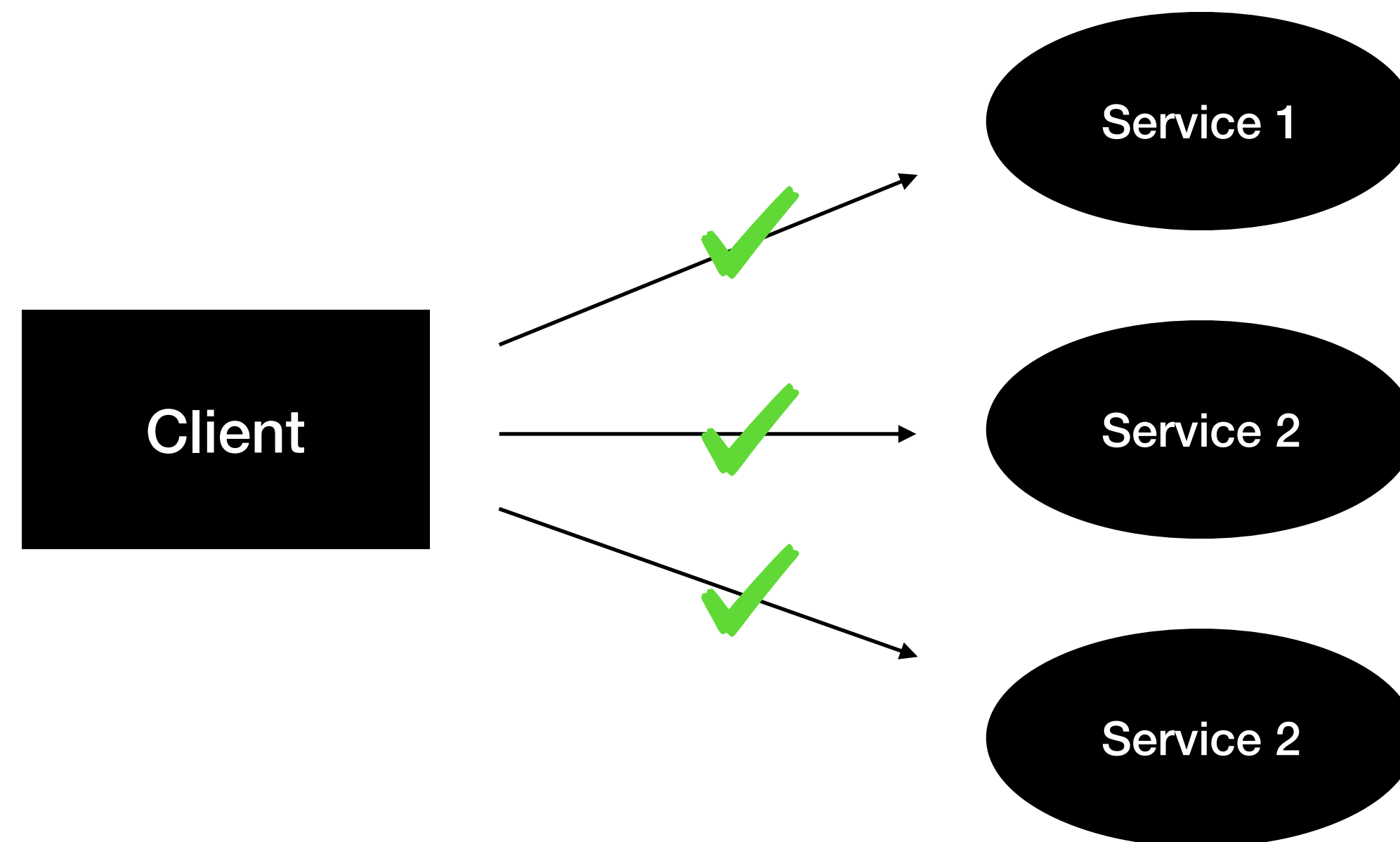
- Spring is one of the popular framework in the Java Community
- **Spring WebClient** is a rest client library that's got released as part of **Spring 5**
- **Spring WebClient** is a functional style RestClient
- **Spring WebClient** can be used as a blocking or non blocking Rest Client

Github Jobs API

allOf()

allOf() - Dealing with Multiple CompletableFutures

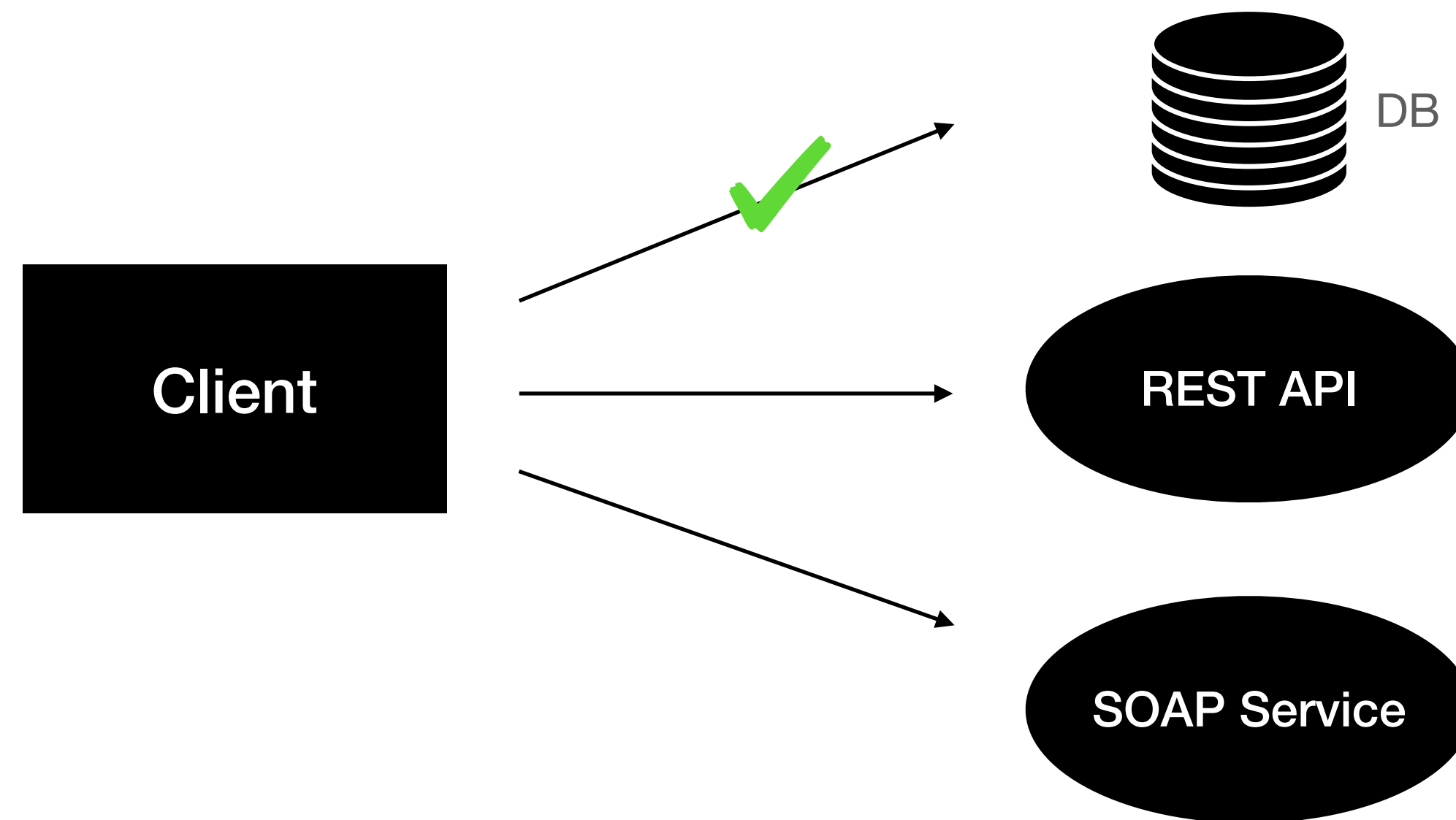
- static method that's part of CompletableFuture API
- Use allOf() when you are dealing with Multiple CompletableFuture



anyOf()

anyOf() - Dealing with Multiple CompletableFutures

- static method that's part of CompletableFuture API
- Use anyOf() when you are dealing with retrieving data from multiple Data Sources



TimeOuts In CompletableFuture

Timeouts in CompletableFuture

- Asynchronous tasks may run indefinitely
- Used to timeout a task in CompletableFuture
- **orTimeout()** in CompletableFutureAPI