Recognize How Parallel Programs are Developed in Java

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Learning Objectives in this Part of the Lesson

- Understand the meaning of key parallel programming concepts
- Know when to apply parallelism
- Recognize how Java supports parallel programming via object-oriented & functional frameworks

See www.dre.vanderbilt.edu/~schmidt/frameworks.html

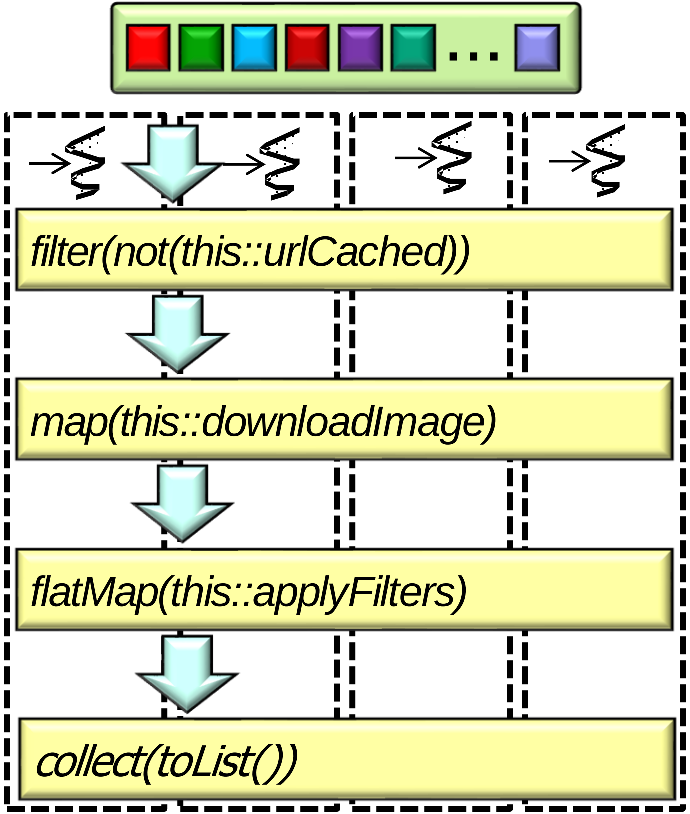
Learning Objectives in this Part of the Lesson

- Recognize the parallelism frameworks supported by Java, e.g.
  - **Fork-join pools**
    - An object-oriented framework

See docs.oracle.com/javase/tutorial/essential/concurrency/forkjoin.html

Learning Objectives in this Part of the Lesson

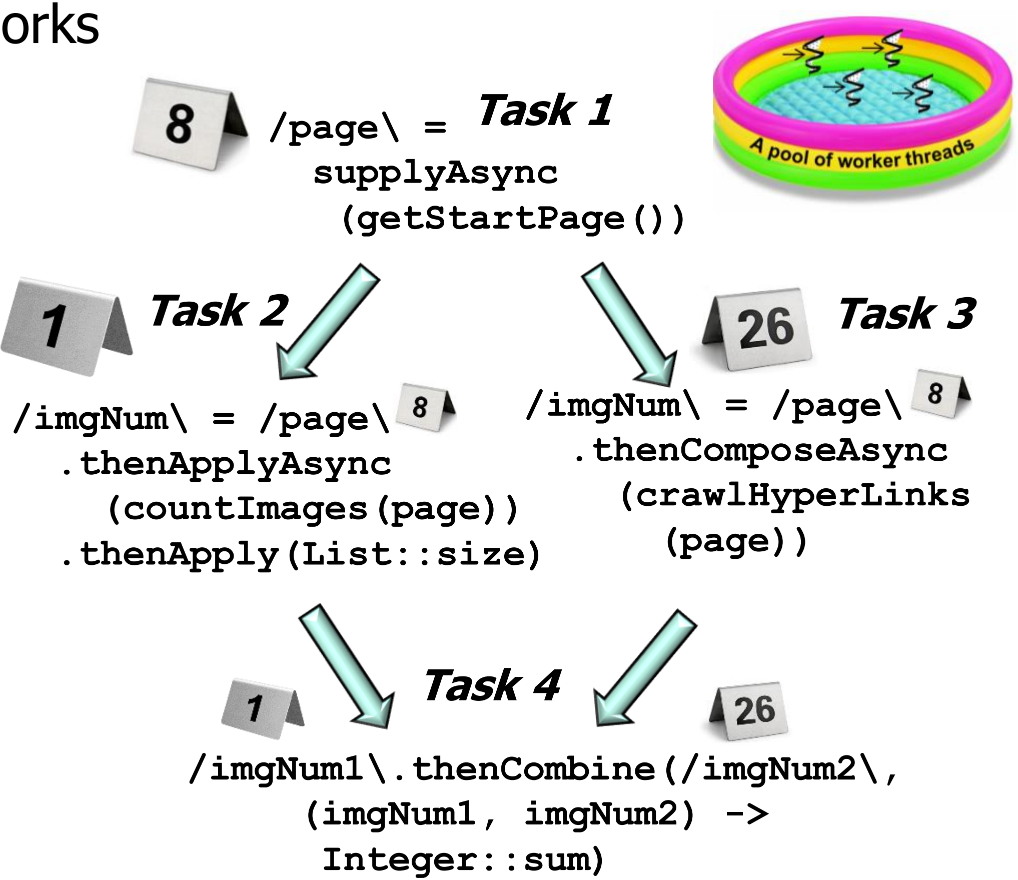
- Recognize the parallelism frameworks supported by Java, e.g.
  - Fork-join pools
  - **Parallel streams**
    - A synchronous functional framework



See docs.oracle.com/javase/tutorial/collections/streams/parallelism.html

Learning Objectives in this Part of the Lesson

- Recognize the parallelism frameworks supported by Java, e.g.
  - Fork-join pools
  - Parallel streams
  - **Completable futures**
    - A reactive/asynchronous functional framework



Task 1

```
/page\ =
  supplyAsync
    (getStartPage())
```

Task 2

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/imgNum\ = /page\
  .thenApplyAsync
    (countImages(page))
  .thenApply(List::size)
```

Task 3

```
/imgNum\ = /page\
  .thenComposeAsync
    (crawlHyperLinks
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```

Task 4

```
/imgNum1\.thenCombine(/imgNum2\,
  (imgNum1, imgNum2) ->
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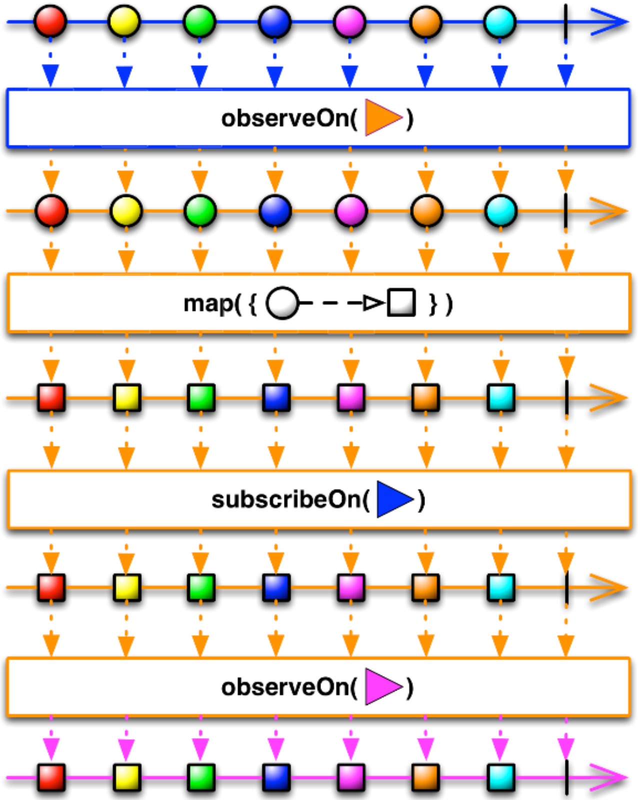
```

See www.callicoder.com/java-8-completablefuture-tutorial

Learning Objectives in this Part of the Lesson

- Recognize the parallelism frameworks supported by Java, e.g.
  - **Fork-join pools**
  - **Parallel streams**
  - **Completable futures**
  - **Reactive streams**
    - An async programming paradigm concerned with processing data streams & propagation of changes



See en.wikipedia.org/wiki/Reactive_Streams

Overview of Java Parallelism Frameworks

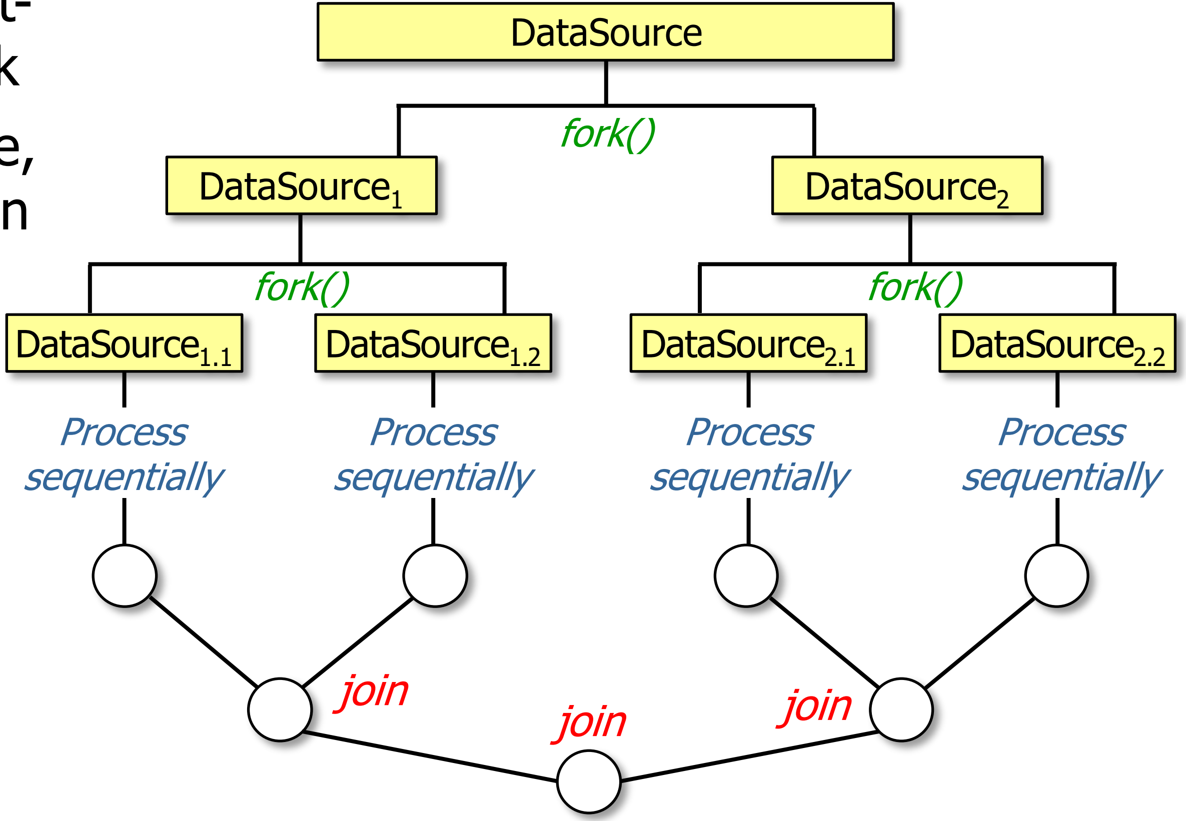
Overview of Java Parallelism Frameworks

- Java 7 introduced the object-oriented fork-join framework

See www.infoq.com/interviews/doug-lea-fork-join

Overview of Java Parallelism Frameworks

- Java 7 introduced the object-oriented fork-join framework
  - Provides high performance, fine-grained task execution for data parallelism

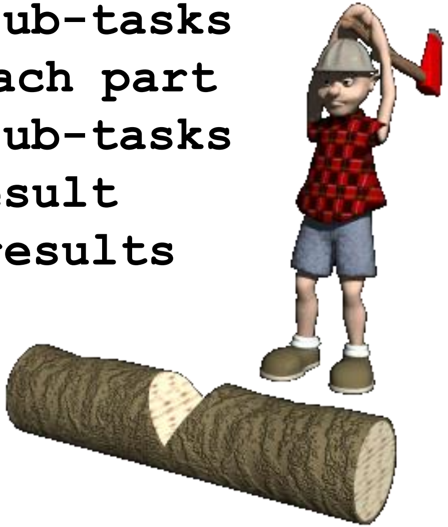


See www.dre.vanderbilt.edu/~schmidt/PDF/DataParallelismInJava.pdf

Overview of Java Parallelism Frameworks

- Java 7 introduced the object-oriented fork-join framework
  - Provides high performance, fine-grained task execution for data parallelism
  - Supports parallel programming by solving problems via "divide & conquer"

```
Result solve(Problem problem) {
  if (problem is small)
    directly solve problem
  else {
    a. split problem into
       independent parts
    b. fork new sub-tasks
       to solve each part
    c. join all sub-tasks
    d. compose result
       from sub-results
  }
}
```



See en.wikipedia.org/wiki/Divide_and_conquer_algorithm

Overview of Java Parallelism Frameworks

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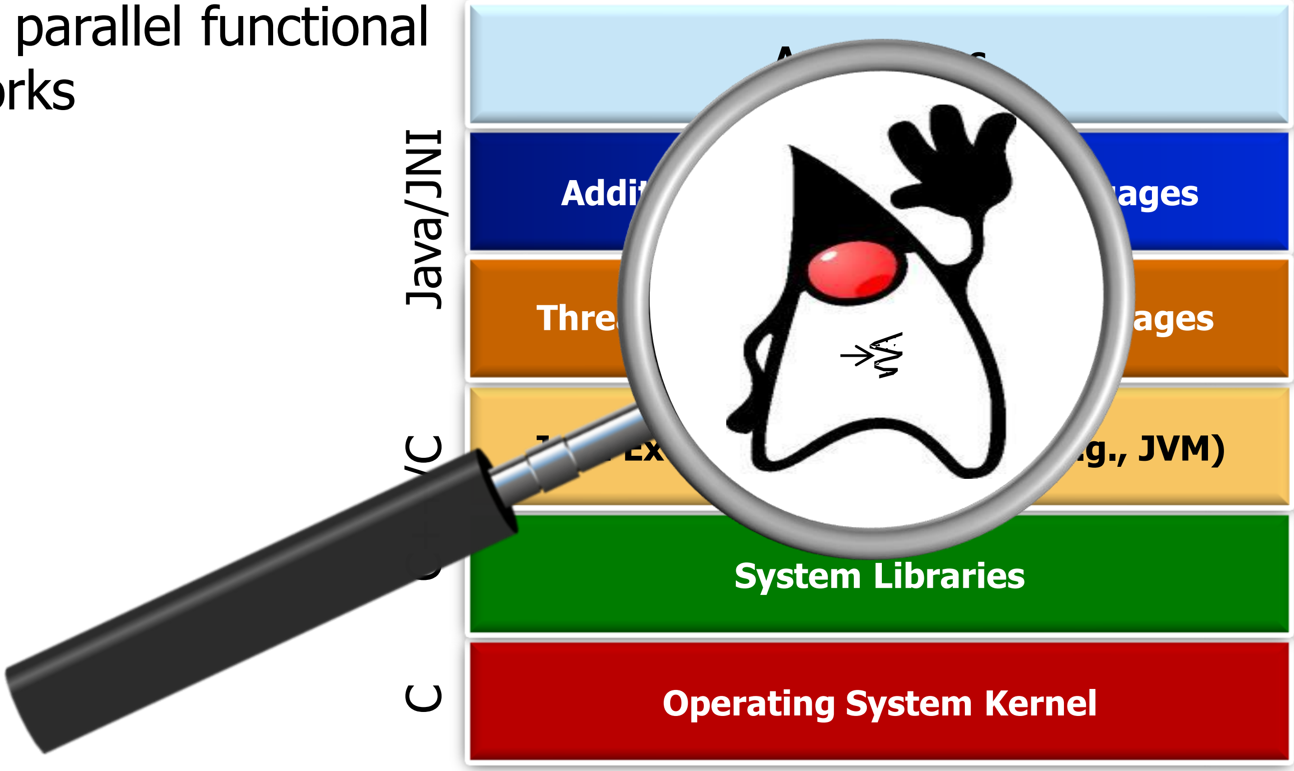
  - Provides high performance, fine-grained task execution for data parallelism
  - Supports parallel programming by solving problems via "divide & conquer"
  - Employs *work-stealing* to optimize multi-core processor performance

See gee.cs.oswego.edu/dl/papers/fj.pdf

Overview of Java Parallelism Frameworks

- Java 8 added two new parallel functional programming frameworks



See www.ibm.com/developerworks/library/j-jvmc2

Overview of Java Parallelism Frameworks

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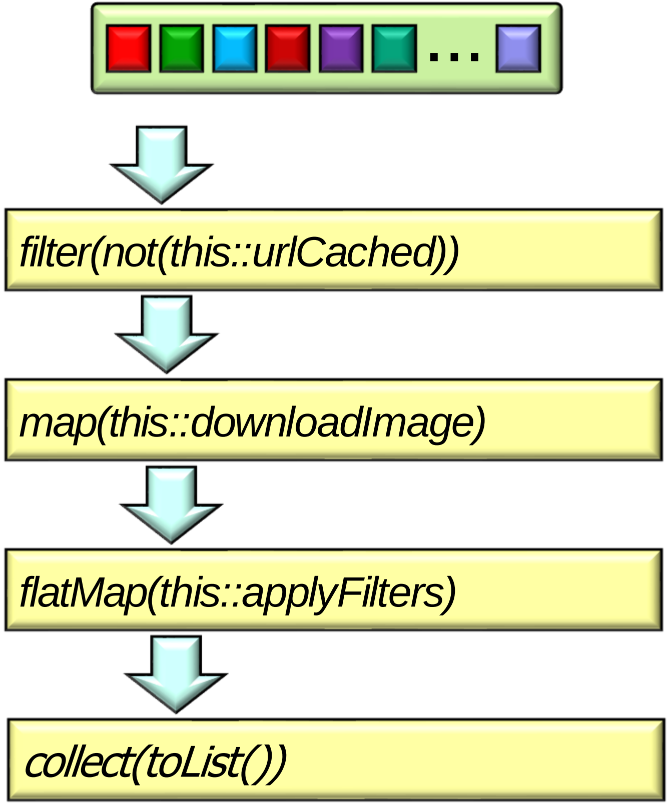
  1. **Parallel streams**



filter(not(this::urlCached))

map(this::downloadImage)

flatMap(this::applyFilters)

collect(toList())

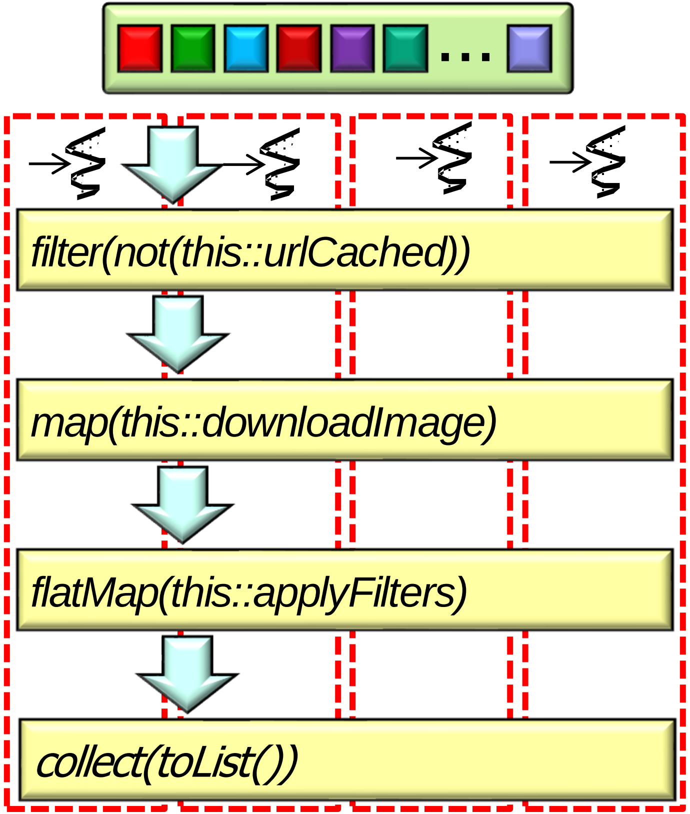
See docs.oracle.com/javase/tutorial/collections/streams/parallelism.html

Overview of Java Parallelism Frameworks

- Java 8 added two new parallel functional programming frameworks

  1. Parallel streams

  - Partitions a stream into multiple substreams that run independently & combine into a "reduced" result

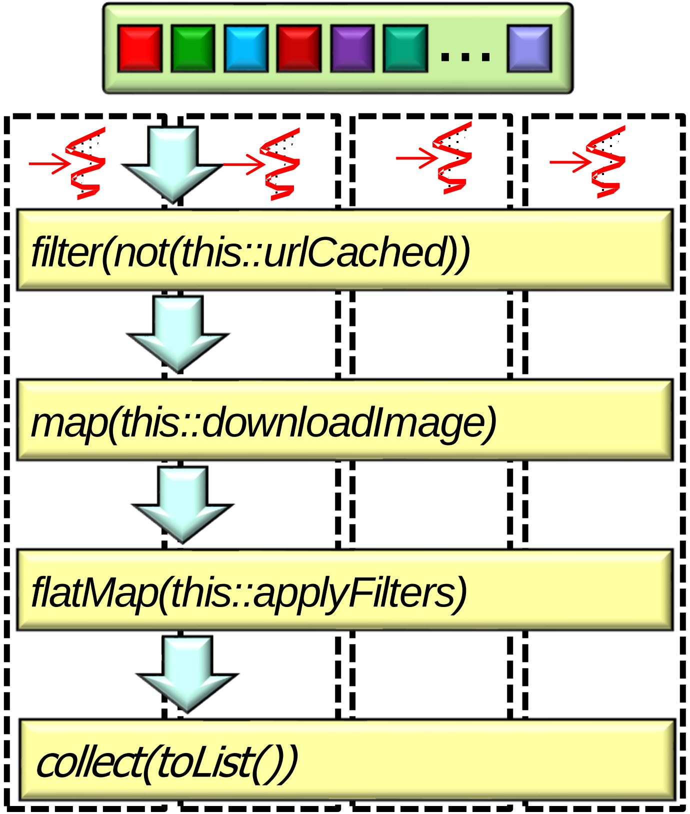


Overview of Java Parallelism Frameworks

- Java 8 added two new parallel functional programming frameworks

  1. Parallel streams

  - Partitions a stream into multiple substreams that run independently & combine into a "reduced" result
  - Chunks of data in the substreams can be mapped to multiple threads (& cores)



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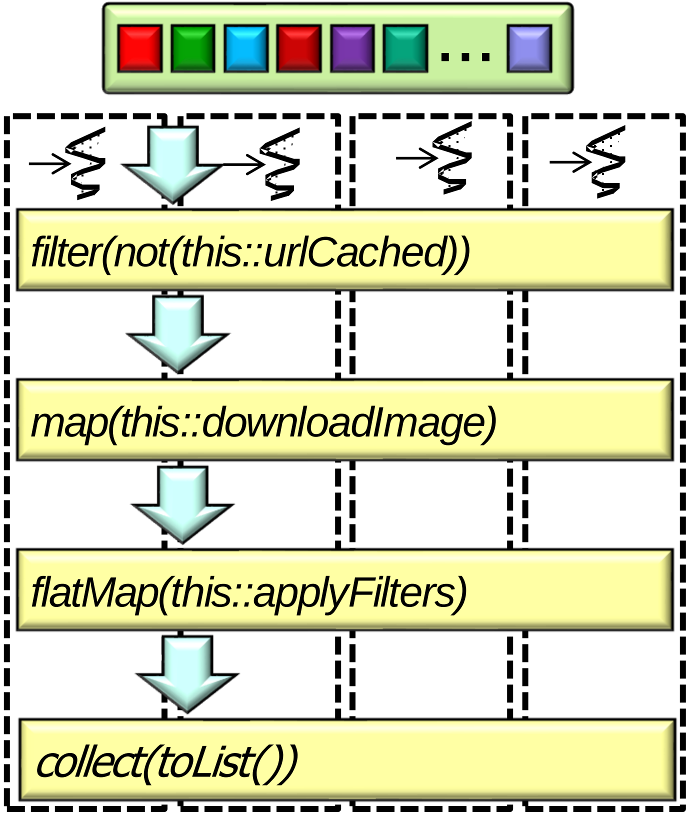
- Partitions a stream into multiple substreams that run independently & combine into a "reduced" result
- Chunks of data in the substreams can be mapped to multiple threads (& cores)
- Leverages the common fork-join pool



See dzone.com/articles/common-fork-join-pool-and-streams

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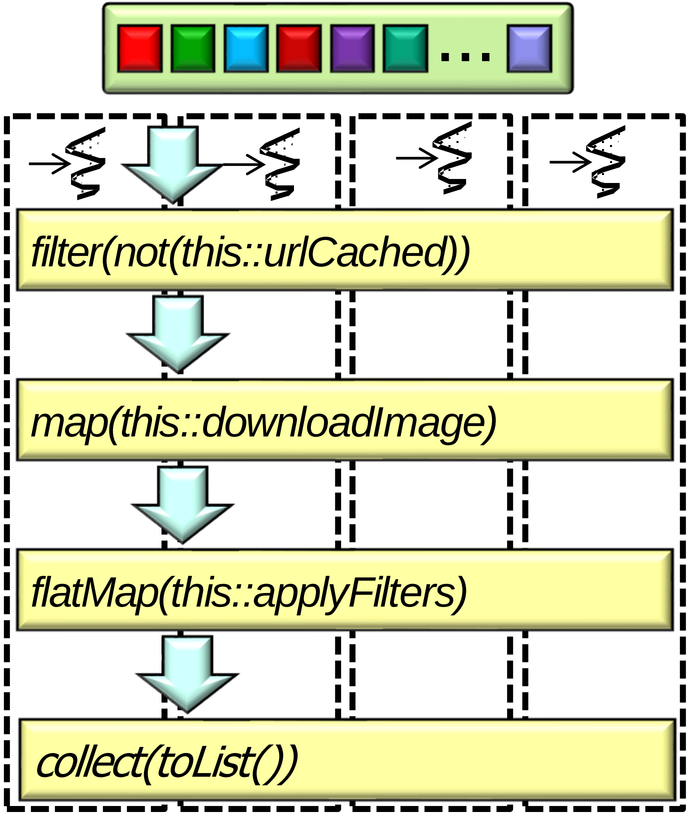

Parallel streams provides fine-grained data parallelism functional programming

Overview of Java Parallelism Frameworks

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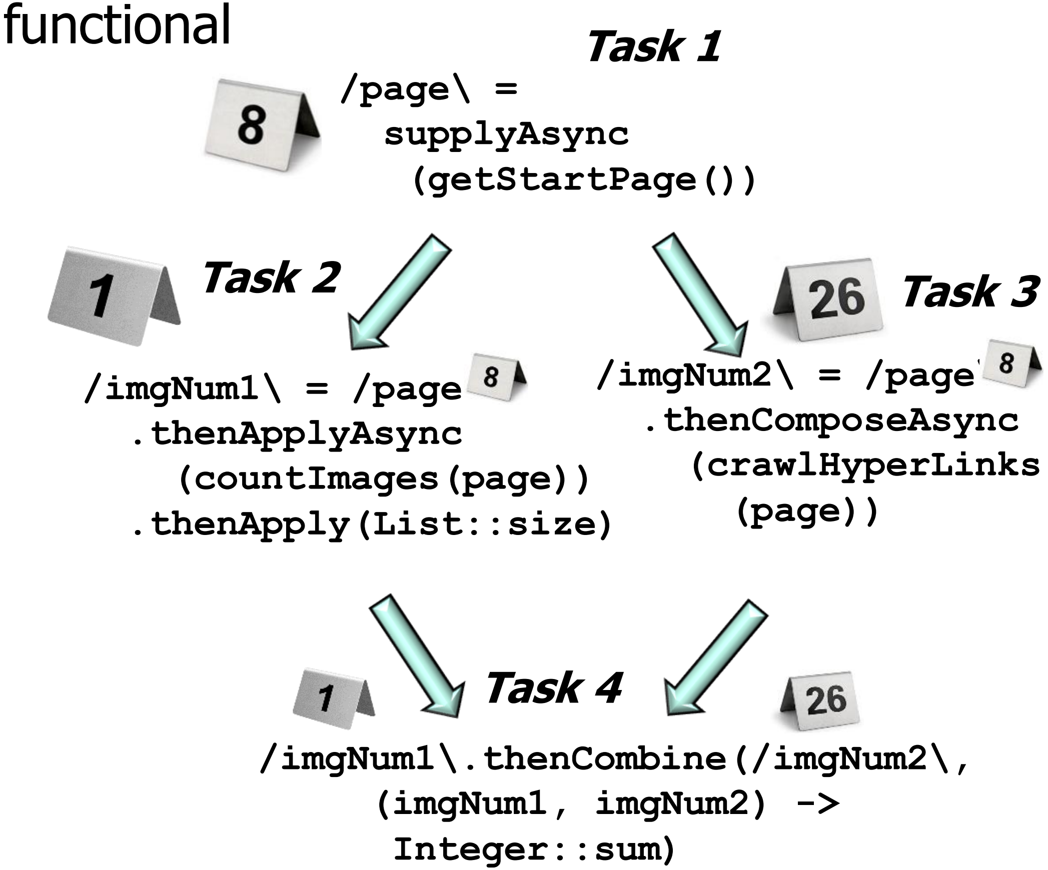
  1. **Parallel streams**

  2. **Completable futures**



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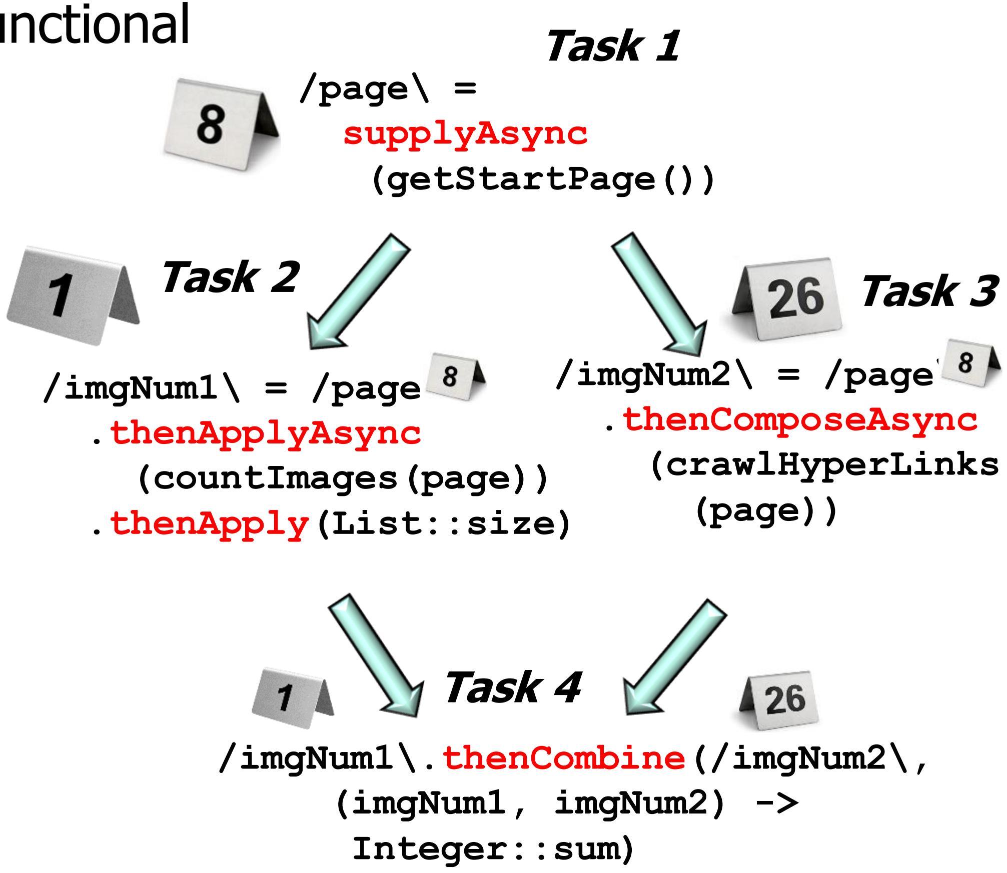
See docs.oracle.com/javase/8/docs/api/java/util/concurrent/CompletableFuture.html

Overview of Java Parallelism Frameworks

- Java 8 added two new parallel functional programming frameworks

1. Parallel streams
2. **Completable futures**
   - Supports dependent actions that trigger upon completion of async operations



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See docs.oracle.com/javase/8/docs/api/java/util/concurrent/CompletionStage.html

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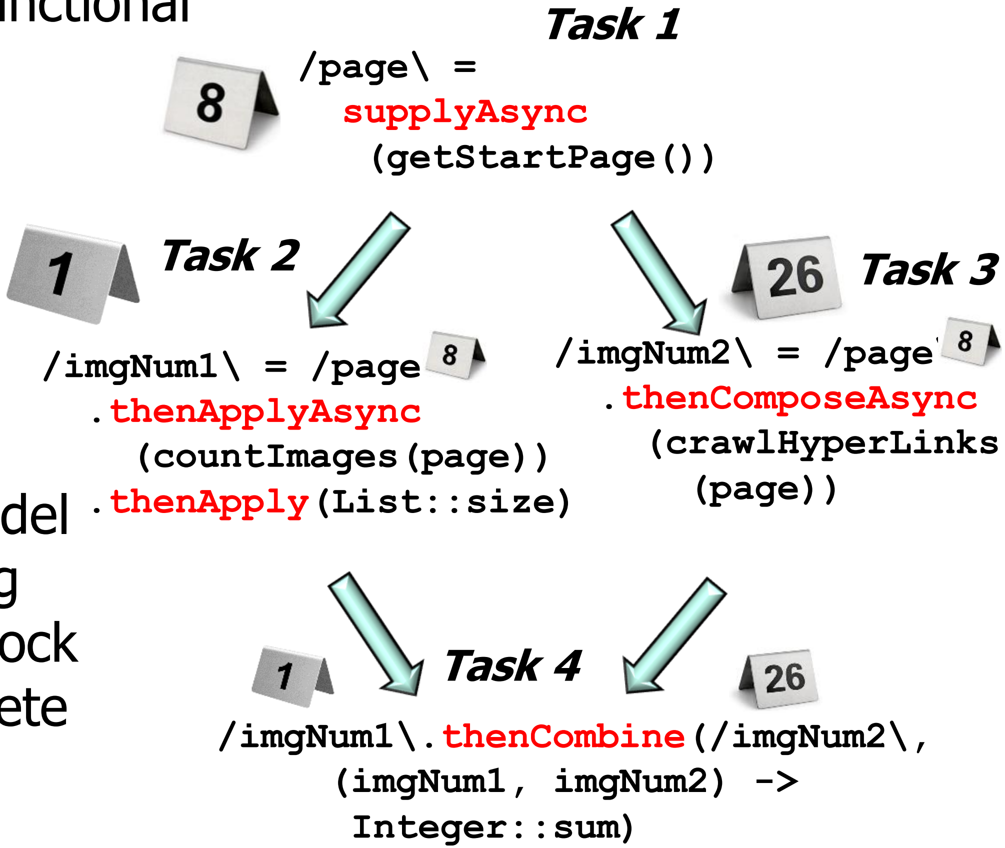
  1. Parallel streams

  2. **Completable futures**

     - Supports dependent actions that trigger upon completion of async operations

       - Async operations are a model of concurrent programming where the caller doesn't block waiting for callee to complete



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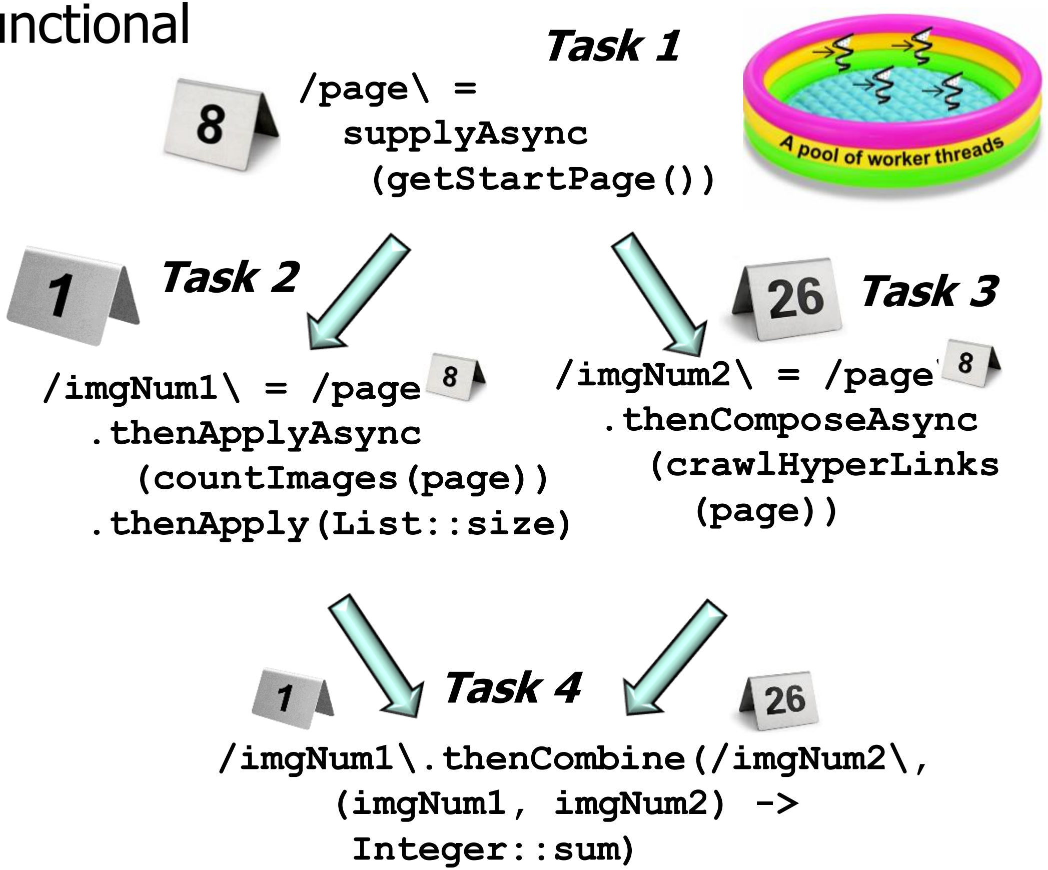
See en.wikipedia.org/wiki/Asynchrony_(computer_programming)

Overview of Java Parallelism Frameworks

- Java 8 added two new parallel functional programming frameworks

1. Parallel streams
2. **Completable futures**
   - Supports dependent actions that trigger upon completion of async operations
   - Async operations can run in parallel in thread pools



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See www.nurkiewicz.com/2013/05/java-8-definitive-guide-to.html

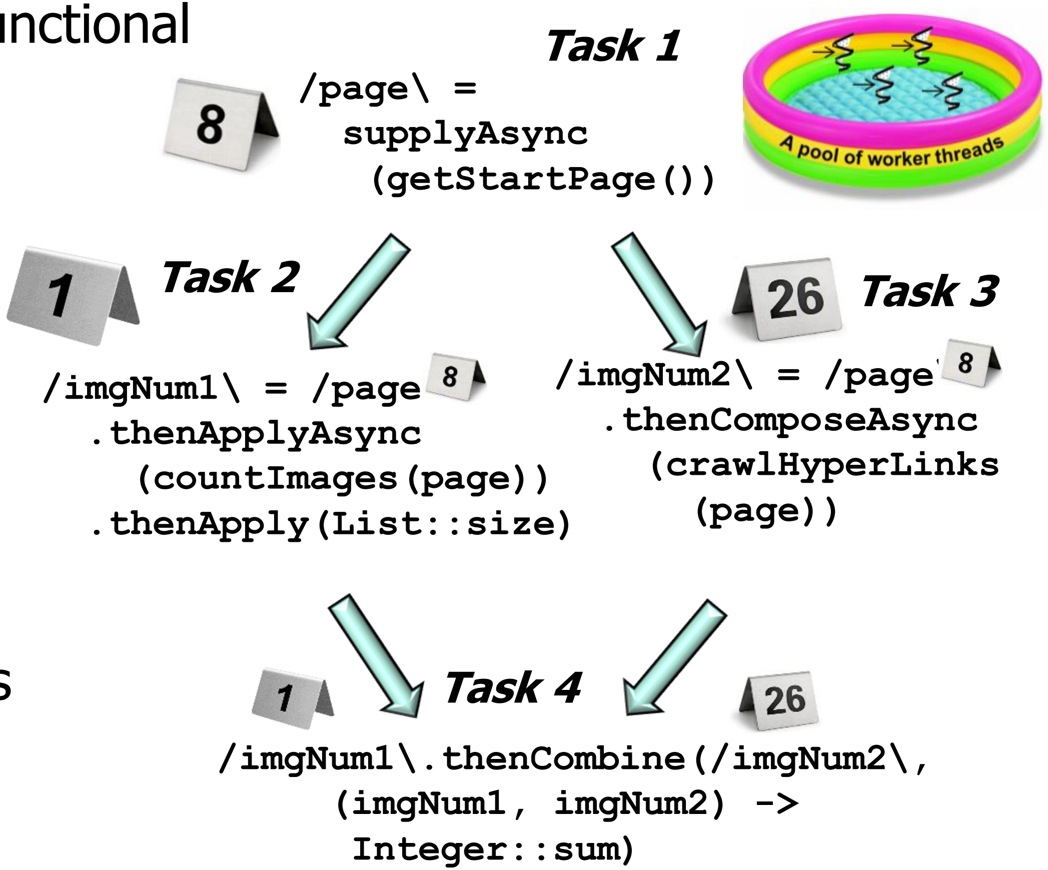
Overview of Java Parallelism Frameworks

- Java 8 added two new parallel functional programming frameworks

  1. Parallel streams

  2. **Completable futures**

     - Supports dependent actions that trigger upon completion of async operations
     - Async operations can run in parallel in thread pools
       - Many types of thread pools can be applied here!



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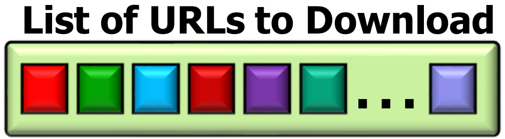
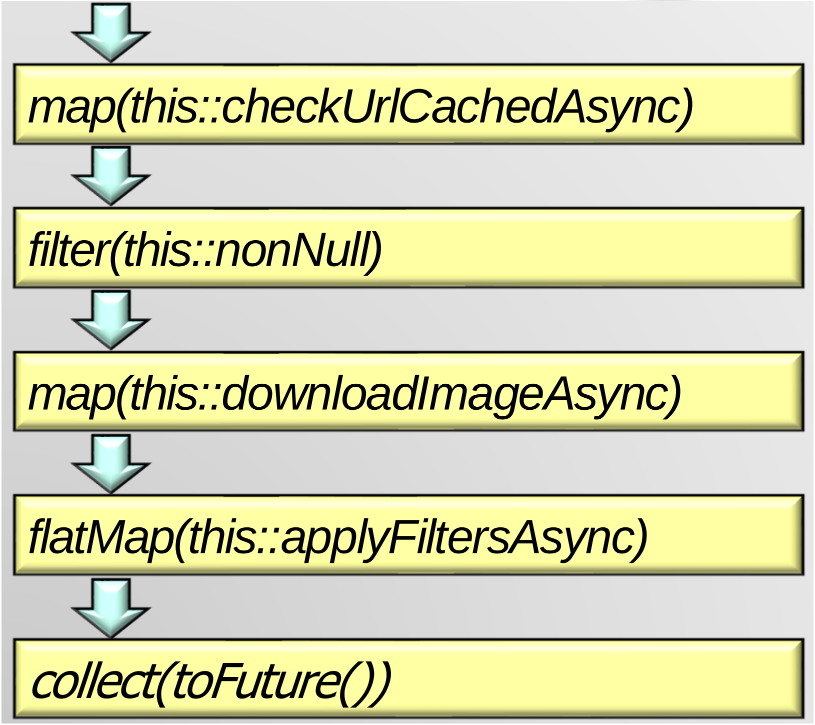




map(this::checkUrlCachedAsync)

filter(this::nonNull)

map(this::downloadImageAsync)

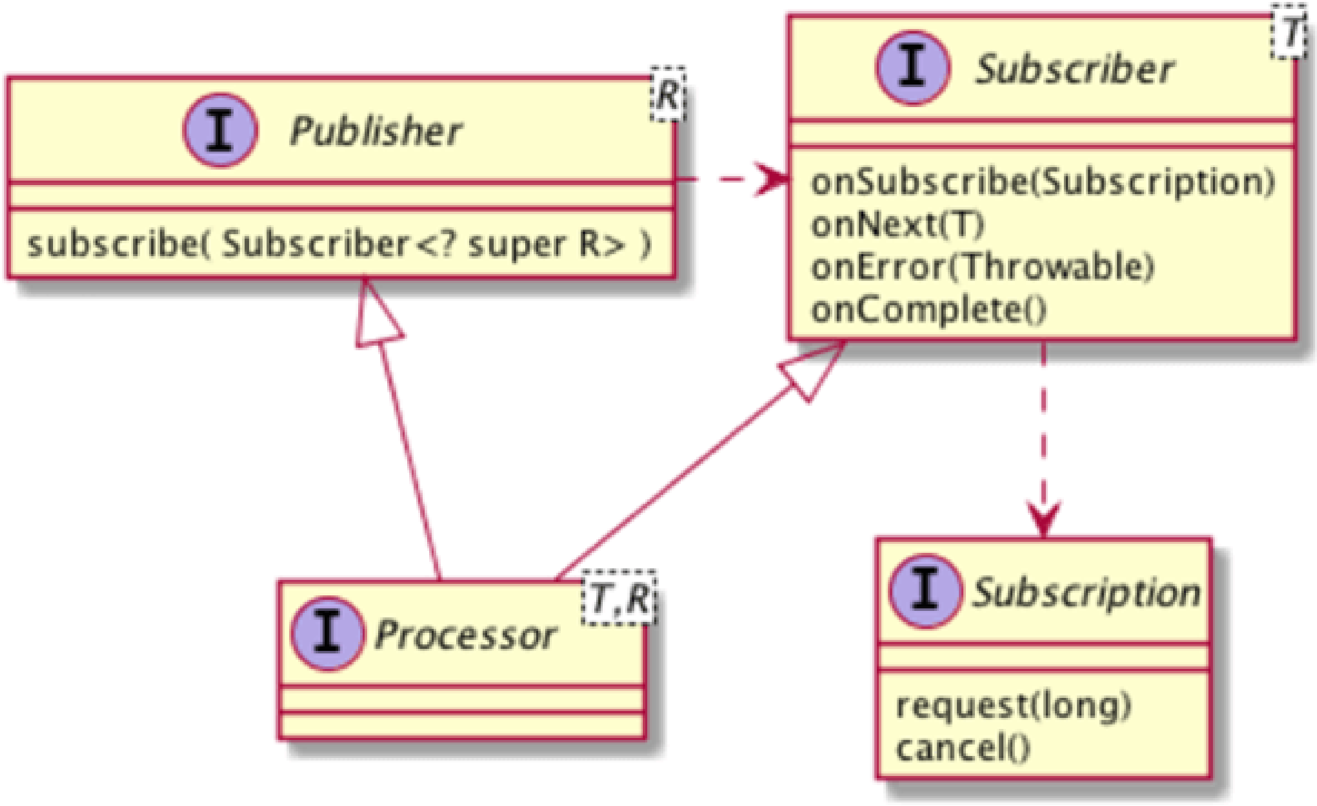
flatMap(this::applyFiltersAsync)

collect(toFuture())

Java completable futures & streams can be combined to good effects!!

Overview of Java Parallelism Frameworks

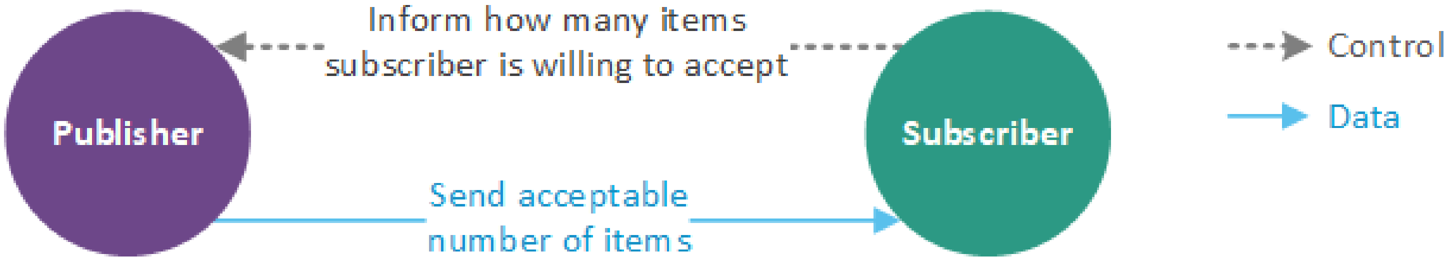
- Java 9 added support for reactive streams via the "Flow" API



See www.reactive-streams.org

Overview of Java Parallelism Frameworks

- Java 9 added support for reactive streams via the “Flow” API
  - Implements a stream-oriented pub/sub framework via two patterns


Inform how many items subscriber is willing to accept
Publisher
Subscriber
Send acceptable number of items
Control
Data

See javasampleapproach.com/java/java-9/java-9-flow-api-example-publisher-and-subscriber

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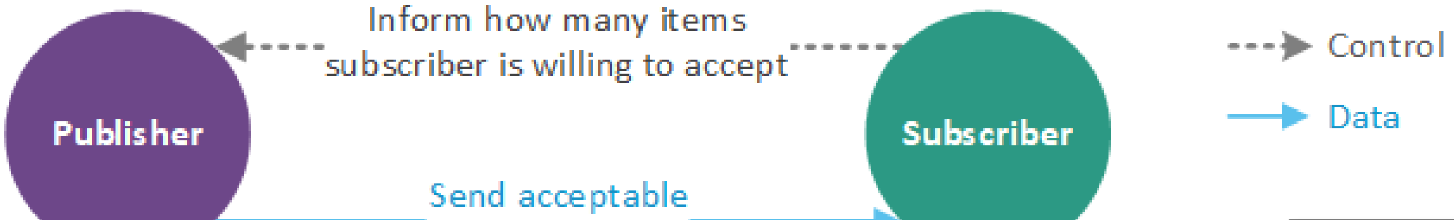
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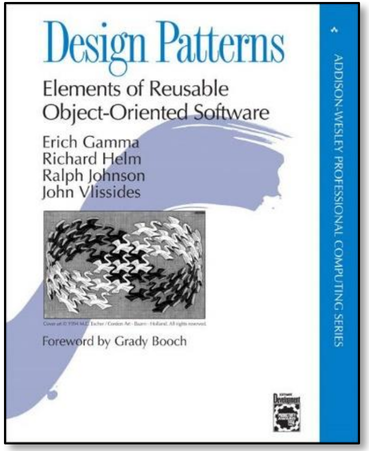
Design Patterns
Elements of Reusable Object-Oriented Software
Erich Gamma
Richard Helm
Ralph Johnson
John Vlissides
Foreword by Grady Booch
ADDISON-WESLEY PROFESSIONAL COMPUTING SERIES

- *Iterator*
  - Applies a "pull model" where apps pull items from a publisher source

See en.wikipedia.org/wiki/Iterator_pattern

Overview of Java Parallelism Frameworks

- Java 9 added support for reactive streams via the "Flow" API
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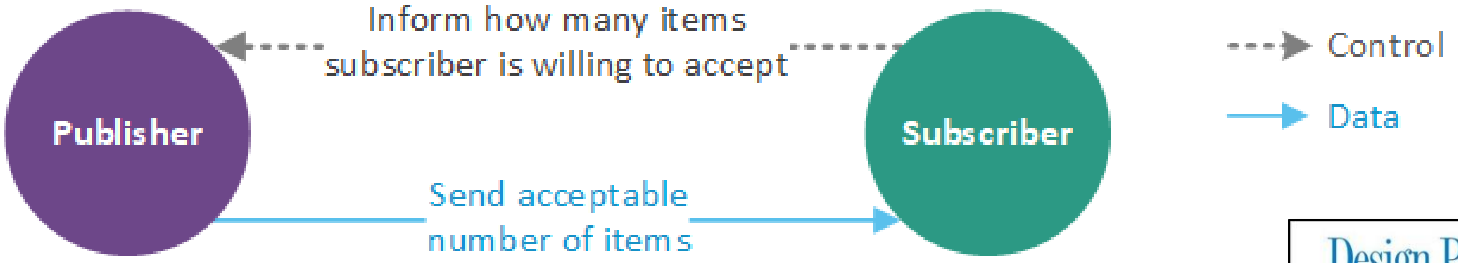
Inform how many items subscriber is willing to accept
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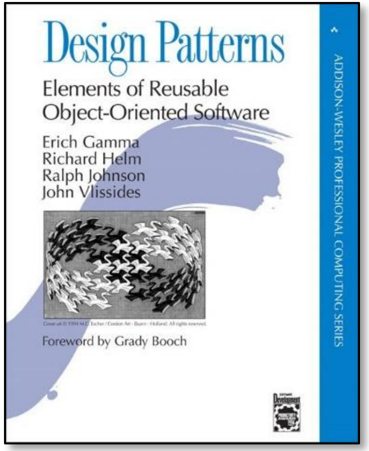
Data

    - *Iterator*
    - *Observer*
      - Applies a "push model" that reacts when a publisher source pushes an item to a subscriber sink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See en.wikipedia.org/wiki/Observer_pattern

Overview of Java Parallelism Frameworks

- Popular reactive streams implementations include RxJava & Project Reactor

See www.baeldung.com/rx-java & projectreactor.io

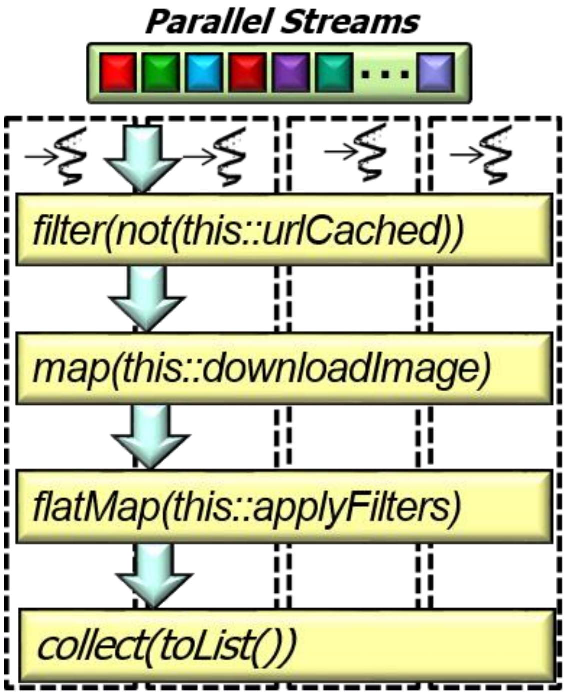
Overview of Java Parallelism Frameworks

- All these Java frameworks can often eliminate the use of synchronization or explicit threading when developing parallel apps!

Alleviates many accidental & inherent complexities of parallel programming

Overview of Java Parallelism Frameworks

- Java parallel streams & completable future functional frameworks use the object-oriented fork-join framework by default



Parallel Streams

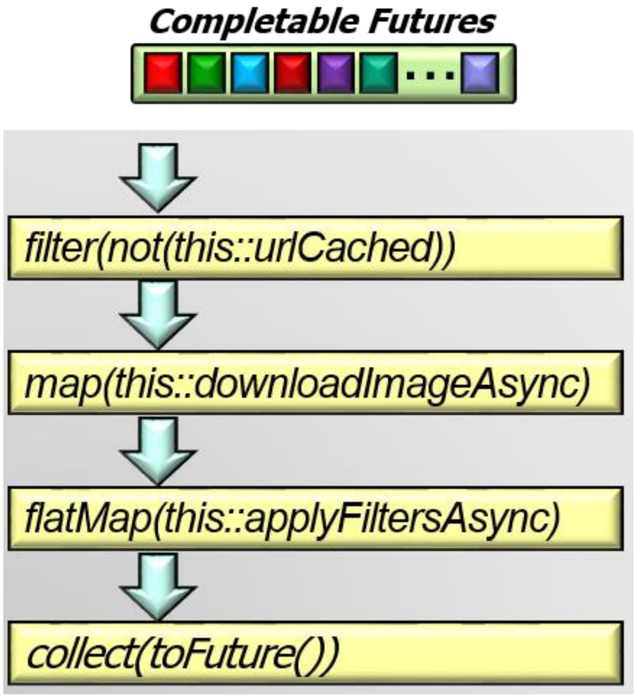
filter(not(this::urlCached))

map(this::downloadImage)

flatMap(this::applyFilters)

collect(toList())

ForkJoinPool



Completable Futures

filter(not(this::urlCached))

map(this::downloadImageAsync)

flatMap(this::applyFiltersAsync)

collect(toFuture())

See www.oracle.com/technetwork/articles/java/fork-join-422606.html

End of Recognize How Parallel Programs Are Developed in Java