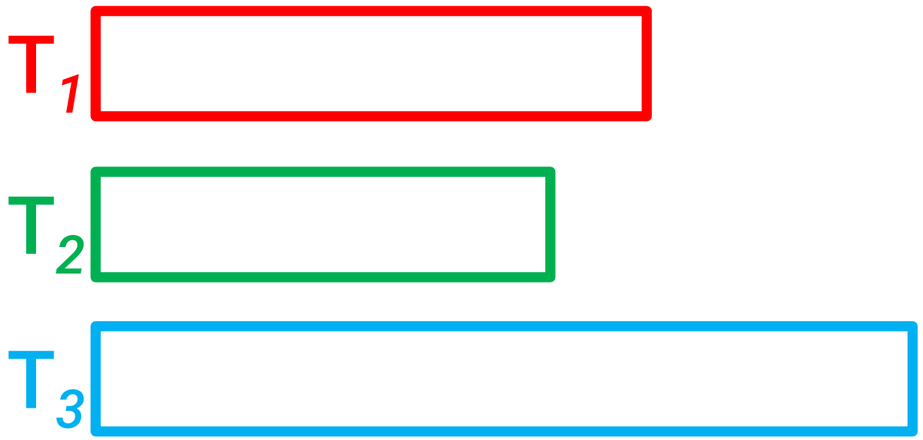

API
asynchronous
8
Java
CompletableFuture
@JosePaumard

Asynchronous?

Asynchronous

Suppose we have three tasks to execute



Asynchronous

1st easy way to execute them:

« synchronous execution »

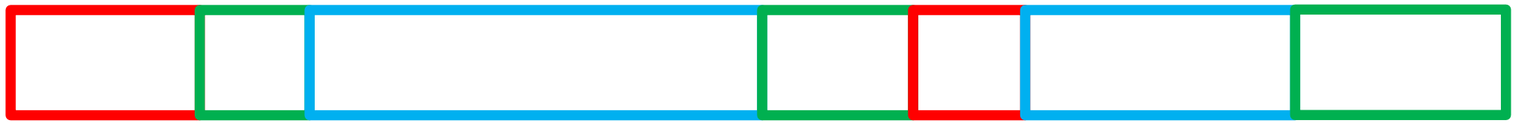
Asynchronous

2nd way to do it:

« multithreaded execution »

Asynchronous

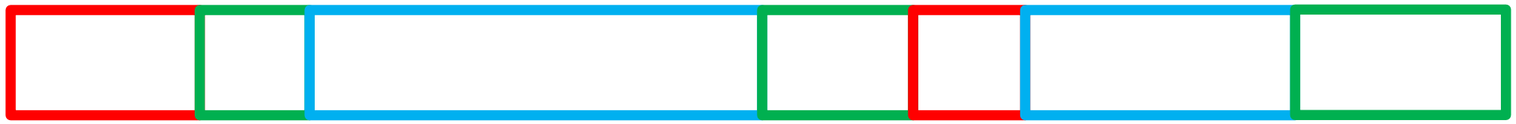
2nd way to do it:



« multithreaded execution » … on only one core

Asynchronous

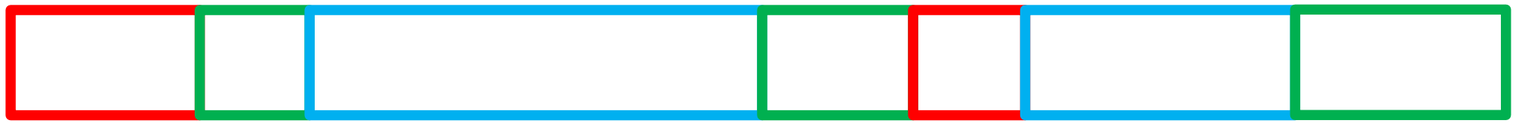
3rd way to do it:



« asynchronous »

Asynchronous

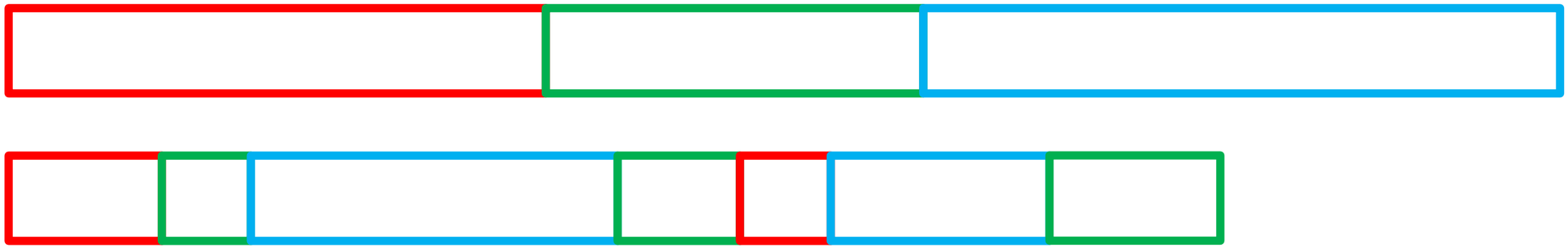
3rd way to do it:



« asynchronous » … even on a multicore

Asynchronous

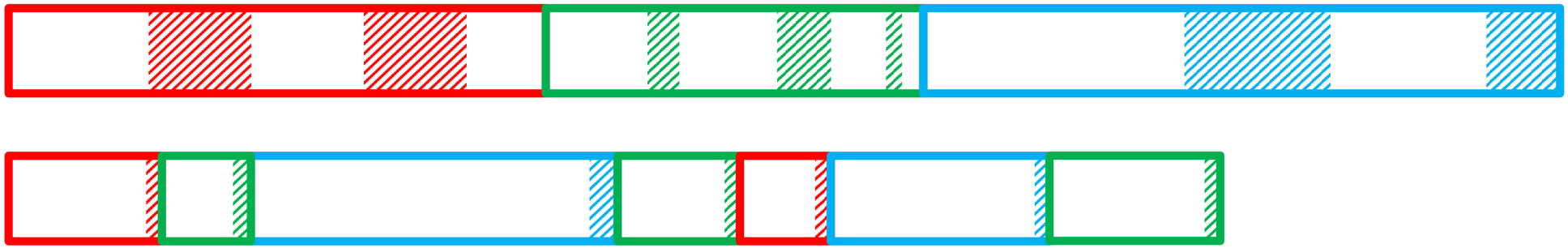
Synchronous vs asynchronous:



Is asynchronous any faster?

Asynchronous

Synchronous vs asynchronous:



Is asynchronous any faster?

Well it can be

Because it is « *non blocking* »

Asynchronous

Difference with the synchronous multithreaded model?

1) The async engine decides to switch from one context to another
2) Single threaded = no issue with atomicity or visibility

Performances?

No multithreaded « ***context switch*** »

Asynchronous

Pattern

```
queryEngine.select("select user from User")
           .forEach(user -> System.out.println(user)) ;
```

Asynchronous

Pattern

```
queryEngine.select("select user from User")
           .forEach(user -> System.out.println(user)) ;
```

Callback or task: lambda expression

Asynchronous

Pattern

```
queryEngine.select("select user from User")
           .forEach(user -> System.out.println(user)) ;
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Callback or task: lambda expression

When the result is available, then we can continue with the next task

Asynchronous

Pattern

```
queryEngine.select("select user from User")
           .forEach(user -> System.out.println(user)) ;
```

Callback or task: lambda expression

When the result is available, then we can continue with the next task

Now how can we write that in Java?

A task in Java

Since Java 1: Runnable

Since Java 5: Callable

In Java 5 we have the ExecutorService (pool of threads)

We give a task and get back a Future

A task in Java

Pattern

```
Callable<String> task = () -> "select user from User" ;
Future<String> future = executorService.submit(task) ;
```

A task in Java

Pattern

```
Callable<String> task = () -> "select user from User" ;
Future<String> future = executorService.submit(task) ;
```

```
List<User> users = future.get() ;     // blocking
users.forEach(System.out::println) ;
```

A task in Java

Pattern

```
Callable<String> task = () -> "select user from User" ;
Future<String> future = executorService.submit(task) ;
```

```
List<User> users = future.get() ;     // blocking
users.forEach(System.out::println) ;
```

Passing an object from one task to another has to be handled in the « master » thread

Asynchronous programming

We have new tools in Java 8 to handle this precise case

It brings new solutions to chain tasks

And can handle both asynchronous and multithreaded programming

José PAUMARD

MCF Um. Paris 13

PhD Appl C.S.

Open source dev.

Independant

@JosePaumard

José PAUMARD

Java magazine
By and for the Java community

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Parleys

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Questions?
#J8Async

Creation of an asynchronous task

Let us see an example first

Creation of an asynchronous task

The Jersey way to create an asynchronous call

```
@Path("/resource")
public class AsyncResource {
    @GET
    public void asyncGet(@Suspended final AsyncResponse asyncResponse) {

        new Thread(new Runnable() {
            public void run() {
                String result = longOperation();
                asyncResponse.resume(result);
            }
        }).start();
    }
}
```

Creation of an asynchronous task

(let us fix this code, this is Java 8)

```
@Path("/resource")
public class AsyncResource {

    @Inject private Executor executor;

    @GET
    public void asyncGet(@Suspended final AsyncResponse asyncResponse) {

        executor.execute(() -> {
            String result = longOperation();
            asyncResponse.resume(result);
        });
    }
}
```

How to test it?

The question is: how can we test that code?

We want to check if the `result` object
is passed to the `resume()` method of the `asyncResponse`

How to test it?

We have mocks for that!

It is a very basic test, but tricky to write since we are in an asynchronous world

How to test it?

Let us give one more look at the code

```
@Path("/resource")
public class AsyncResource {
    @GET
    public void asyncGet(@Suspended final AsyncResponse asyncResponse) {

        executor.execute(() -> { // executed in the main thread
            String result = longOperation(); // executed in another thread
            asyncResponse.resume(result);
        });
    }
}
```

How to test it?

We have mocks to check if resume() is properly called with result

It is a very basic test, but tricky to write since we are in an asynchronous world

How to test it?

We can inject a mock `AsyncResponse`, even mock the result

```
@Path("/resource")
public class AsyncResource {
    @GET
    public void asyncGet(@Suspended final AsyncResponse asyncResponse) {

        executor.execute(() -> {
            String result = longOperation();
            asyncResponse.resume(result);
        });
    }
}
```

How to test it?

We can inject a mock `AsyncResponse`, even mock the result

Then verify the correct interaction:

```
Mockito.verify(mockAsyncResponse).resume(result);
```

But:

- we need to verify this once the `run()` method has been called

How to test it?

We can inject a mock `AsyncResponse`, even mock the result

Then verify the correct interaction:

```
Mockito.verify(mockAsyncResponse).resume(result);
```

But:

- we need to verify this once the `run()` method has been called
- and take into account the multithreaded aspect… the read / writes on the mock should be « visible »!

How to test it?

So our constraints are the following:

- we need to verify this once the `run()` method has been called
- we need to read / write on our mocks in the same thread as the one which runs the task we want to test

How to test it?

This is where `CompletionStage` comes to the rescue!

```
@Path("/resource")
public class AsyncResource {

   @Inject ExecutorService executor;

   @GET
   public void asyncGet(@Suspended final AsyncResponse asyncResponse) {

       executor.submit(() -> {
          String result = longOperation();
          asyncResponse.resume(result);
       });
   }
}
```

How to test it?

This pattern:

```
executor.submit(() -> {
            String result = longOperation();
            asyncResponse.resume(result);
        });
```

How to test it?

This pattern:

```
executor.submit(() -> {
            String result = longOperation();
            asyncResponse.resume(result);
        });
```

Becomes this one:

```
CompletableFuture.runAsync(() -> {
            String result = longOperation();
            asyncResponse.resume(result);
        }, executor);
```

And does basically the same thing

How to test it?

But the nice thing is:

```
CompletableFuture<Void> completableFuture =
CompletableFuture.runAsync(() -> {
          String result = longOperation();
          asyncResponse.resume(result);
      }, executor);
```

How to test it?

But the nice thing is:

```
CompletableFuture<Void> completableFuture =
CompletableFuture.runAsync(() -> {
          String result = longOperation();
          asyncResponse.resume(result);
      }, executor);
```

And on this object we can call:

```
completableFuture
   .thenRun(() -> {
      Mockito.verify(mockAsyncResponse).resume(result);
   }
);
```

How to test it?

Be careful of visibility issues

1) It’s simpler to run everything in the same thread
2) Create, train and check our mocks in this thread

CompletionStage / CompletableFuture

Two elements in this API:

- an interface: CompletionStage
- an implementing class: CompletableFuture

The interface depends on CompletableFuture:

```
public CompletableFuture<T> toCompletableFuture();
```

What is a CompletionStage?

A model for a task:

- that performs an action an may return a value when another completion stage completes
- that may trigger other tasks

So a completion stage is an element of a chain

What is a CompletableFuture?

A class that implements both Future and CompletionStage

What is a CompletableFuture?

A class that implements both Future and CompletionStage

It has a state:

- the task may be running
- the task may have complete normally
- the task may have complete exceptionnaly

Methods from Future

Five methods:

```
boolean cancel(boolean mayInterruptIfRunning) ;
```

Methods from Future

Five methods:

```
boolean cancel(boolean mayInterruptIfRunning) ;
```

```
boolean isCanceled() ;
boolean isDone() ;
```

Methods from Future

Five methods:

```
boolean cancel(boolean mayInterruptIfRunning) ;
```

```
boolean isCanceled() ;
boolean isDone() ;
```

```
V get() ;                                          // blocking call
V get(long timeout, TimeUnit timeUnit) ; // may throw a checked exception
    throws InterruptedException, ExecutionException, TimeoutException ;
```

More from CompletableFuture

Future-like methods:

```
V join() ;                          // may throw an unchecked exception
V getNow(V valueIfAbsent) ; // returns immediately
```

More from CompletableFuture

Future-like methods:

```
V join() ;                        // may throw an unchecked exception
V getNow(V valueIfAbsent) ; // returns immediately
```

```
boolean complete(V value) ;  // sets the returned value is not returned
void obtrudeValue(V value) ; // resets the returned value
```

More from CompletableFuture

Future-like methods:

```
V join() ;                      // may throw an unchecked exception
V getNow(V valueIfAbsent) ; // returns immediately
```

```
boolean complete(V value) ;  // sets the returned value is not returned
void obtrudeValue(V value) ; // resets the returned value
```

```
boolean completeExceptionnaly(Throwable t) ;  // sets an exception
void obtrudeException(Throwable t) ;          // resets with an exception
```

How to create a CompletableFuture?

A completed CompletableFuture

```
public static <U> CompletableFuture<U> completedFuture(U value) ;
```

How to create a CompletableFuture?

A CompletableFuture from a Runnable or a Supplier

```
public static CompletableFuture<Void>
    runAsync(Runnable runnable, Executor executor) ;

public static <U> CompletableFuture<U>
    supplyAsync(Supplier<U> value, Executor executor) ;
```

Building CompletionStage chains

A CompletionStage is a step in a chain

- it can be triggered by a previous CompletionStage
- it can trigger another CompletionStage

- it can be executed in a given Executor

Building CompletionStage chains

What is a task?

- it can be a Function
- it can be a Consumer
- it can be a Runnable

Building CompletionStage chains

What kind of operation does it support?

- chaining (1 – 1)
- composing (1 – 1)
- combining, waiting for both result (2 – 1)
- combining, triggered on the first available result (2 – 1)

Building CompletionStage chains

What kind of operation does it support?

- chaining (1 – 1)
- composing (1 – 1)
- combining, waiting for both result (2 – 1)
- combining, triggered on the first available result (2 – 1)

All this gives… 36 methods!

Building CompletionStage chains

In what thread can it be executed?

- In the same executor as the caller
- In a new executor, passed as a parameter
- Asynchronously, *ie* in the common fork join pool

All this gives… 36 methods!

CompletionStage – patterns

Some 1 – 1 patterns

```
public <U> CompletionStage<U>
   thenApply(Function<? super T,? extends U> fn);
```

CompletionStage – patterns

Some 1 – 1 patterns

```
public <U> CompletionStage<U>
   thenApply(Function<? super T,? extends U> fn);
```

```
public CompletionStage<Void>
   thenRunAsync(Runnable action, Executor executor);
```

CompletionStage – patterns

Some 1 – 1 patterns

```
public <U> CompletionStage<U>
   thenApply(Function<? super T,? extends U> fn);
```

```
public CompletionStage<Void>
   thenRunAsync(Runnable action, Executor executor);
```

```
public CompletionStage<Void>
   thenComposeAsync(
        Function<? super T, ? extends CompletionStage<U>> fn);
```

CompletionStage – patterns

Some 2 – 1 patterns

```
public <U, V> CompletionStage<V> thenCombineAsync
    (CompletionStage<U> other,
     BiFunction<T, U, V> function) ;
```

CompletionStage – patterns

Some 2 – 1 patterns

```
public <U, V> CompletionStage<V> thenCombineAsync
   (CompletionStage<U> other,
    BiFunction<T, U, V> function) ;
```

```
public <U> CompletionStage<Void> thenAcceptBoth
   (CompletionStage<U> other,
    BiConsumer<T, U> action) ;
```

CompletionStage – patterns

Some 2 – 1 patterns

```
public <U, V> CompletionStage<V> thenCombineAsync
   (CompletionStage<U> other,
    BiFunction<T, U, V> function) ;
```

```
public <U> CompletionStage<Void> thenAcceptBoth
   (CompletionStage<U> other,
    BiConsumer<T, U> action) ;
```

```
public CompletionStage<Void> runAfterBothAsync
   (CompletionStage<?> other,
    Runnable action, Executor executor) ;
```

CompletionStage – patterns

Some more 2 – 1 patterns

```
public <U> CompletionStage<U> applyToEither
    (CompletionStage<? extends T> other,
     Function<T, U> function) ;
```

CompletionStage – patterns

Some more 2 – 1 patterns

```
public <U> CompletionStage<U> applyToEither
   (CompletionStage<? extends T> other,
    Function<T, U> function) ;
```

```
public CompletionStage<Void> acceptEitherAsync
   (CompletionStage<? extends T> other,
    Consumer<? extends T> consumer) ;
```

CompletionStage – patterns

Some more 2 – 1 patterns

```
public <U> CompletionStage<U> applyToEither
   (CompletionStage<? extends T> other,
    Function<T, U> function) ;
```

```
public CompletionStage<Void> acceptEitherAsync
   (CompletionStage<? extends T> other,
    Consumer<? extends T> consumer) ;
```

```
public CompletionStage<Void> runAfterEitherAsync
   (CompletionStage<U> other,
    Runnable action, Executor executor) ;
```

Back to our first example

So the complete pattern becomes this one

1) First we create our mocks

```
String result = Mockito.mock(String.class);
AsyncResponse response = Mockito.mock(AsyncResponse.class);

Runnable train =  () -> Mockito.doReturn(result).when(response).longOperation();
Runnable verify = () -> Mockito.verify(response).resume(result);
```

Back to our first example

So the complete pattern becomes this one

2) Then we create the call & verify

```
Runnable callAndVerify = () -> {
   asyncResource.executeAsync(response).thenRun(verify);
}
```

Back to our first example

So the complete pattern becomes this one

3) Then we create the task

```
ExecutorService executor = Executors.newSingleThreadExecutor();

AsyncResource asyncResource = new AsyncResource();
asyncResource.setExecutorService(executor);

CompletableFuture
   .runAsync(train, executor)                    // this trains our mocks
   .thenRun(callAndVerify);                      // this verifies our mocks
```

Back to our first example

Since a `CompletableFuture` is also a `Future`, we can fail with a timeout if the test does not complete fast enough

```
ExecutorService executor = Executors.newSingleThreadExecutor();

AsyncResource asyncResource = new AsyncResource();
asyncResource.setExecutorService(executor);

CompletableFuture
    .runAsync(train, executor)                    // this trains our mocks
    .thenRun(callAndVerify)                       // this verifies our mocks
    .get(10, TimeUnit.SECONDS);
```

A second example

Async analysis of a web page

```
CompletableFuture.supplyAsync(
   () -> readPage("http://whatever.com/")
)
```

A second example

Async analysis of a web page

```
CompletableFuture.supplyAsync(
    () -> readPage("http://whatever.com/")
)
.thenApply(page -> linkParser.getLinks(page))
```

A second example

Async analysis of a web page

```
CompletableFuture.supplyAsync(
   () -> readPage("http://whatever.com/")
)
.thenApply(page -> linkParser.getLinks(page))
.thenAccept(
   links -> displayPanel.display(links) // in the right thread!

) ;
```

A second example

Async analysis of a web page

```
CompletableFuture.supplyAsync(
    () -> readPage("http://whatever.com/")
)
.thenApply(page -> linkParser.getLinks(page))
.thenAcceptAsync(
    links -> displayPanel.display(links),
    executor
) ;
```

A second example

Async analysis of a web page

```
public interface Executor {

   void execute(Runnable command);
}
```

A second example

Async analysis of a web page

```
public interface Executor {

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}
```

```
Executor executor = runnable -> SwingUtilities.invokeLater(runnable) ;
```

A second example

Async analysis of a web page

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CompletableFuture.supplyAsync(
   () -> readPage("http://whatever.com/")
)
.thenApply(page -> linkParser.getLinks(page))
.thenAcceptAsync(
   links -> displayPanel.display(links),
   runnable -> SwingUtilities.invokeLater(runnable)
) ;
```

A second example

Async analysis of a web page

```
CompletableFuture.supplyAsync(
   () -> readPage("http://whatever.com/")
)
.thenApply(Parser::getLinks)
.thenAcceptAsync(
   DisplayPanel::display,
   SwingUtilities::invokeLater
) ;
```

A last example

Async events in CDI

```
@Inject
Event<String> event ;

event.fire("some event") ; // returns void
```

```
public void observes(@Observes String payload) {
   // handle the event, called in the firing thread
}
```

A last example

Async events in CDI

```
public void observes(@Observes String payload) {
   // handle the event, called in the firing thread
   CompletableFuture.anyOf(/* some task */) ;
}
```

A last example

Async events in CDI

```
@Inject
Event<String> event ;

event.fireAsync("some event") ; // returns CompletionStage<Object>
```

```
public void observes(@ObservesAsync String payload) {
   // handle the event in another thread
}
```

A last example

Async events in CDI

```
@Inject
Event<String> event ;

Executor executor = SwingUtilities::invokeLater


event.fireAsync("some event", executor) ;
```

A last example

Async events in CDI

```
@Inject
Event<String> event ;

Executor executor = SwingUtilities::invokeLater

CompletionStage<Object> cs =
event.fireAsync("some event", executor) ;

cs.whenComplete(...); // handle the exceptions
```

CompletionStage – last patterns

Static methods

```
public static CompletableFuture<Void>
   allOf(CompletableFuture<?>... cfs) ;
```

```
public static CompletableFuture<Object>
   anyOf(CompletableFuture<?>... cfs) ;
```

Exception handling

So, a CompletableFuture can depend on:

1) one CompletableFuture
2) two CompletableFuture
3) *N* CompletableFuture

Exception handling

So, a CompletableFuture can depend on:

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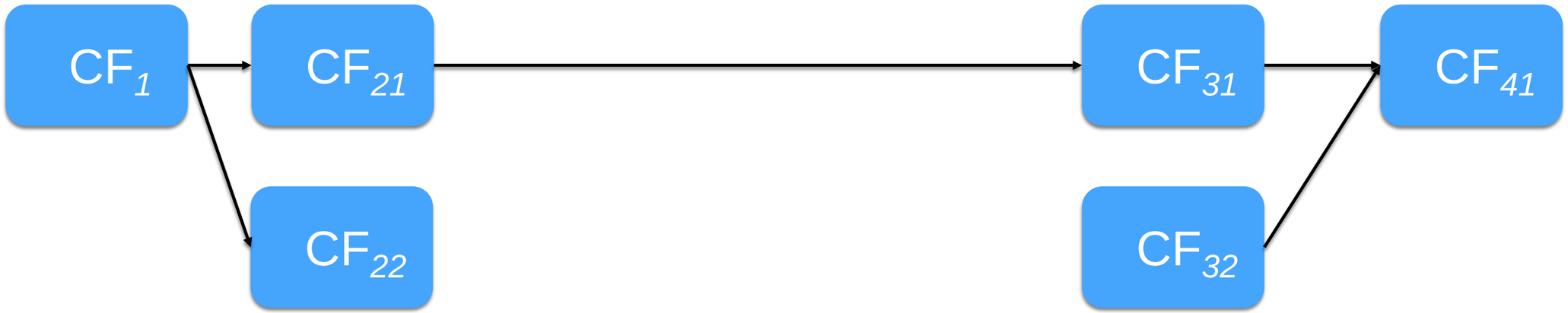
3) *N* CompletableFuture

What happens when an exception is thrown?

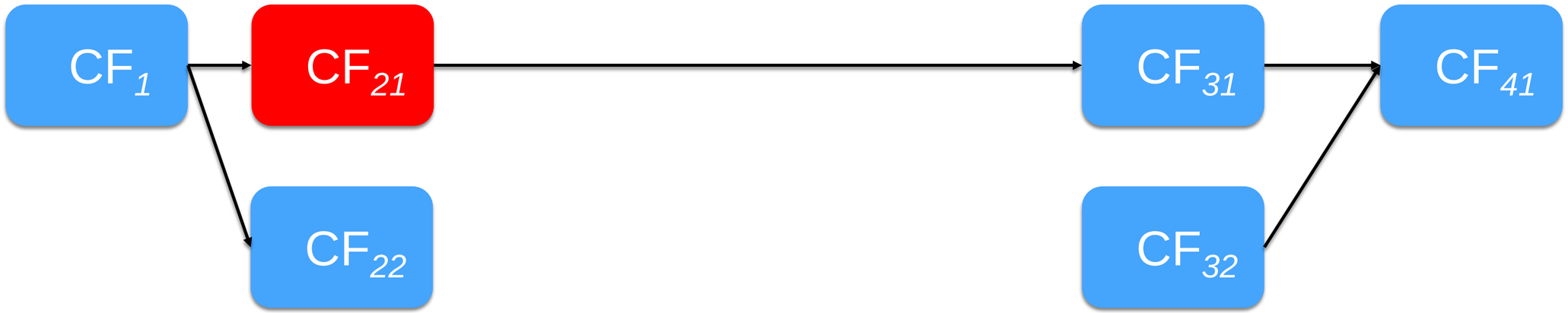
Exception handling

Suppose we have this CF pipeline



Exception handling

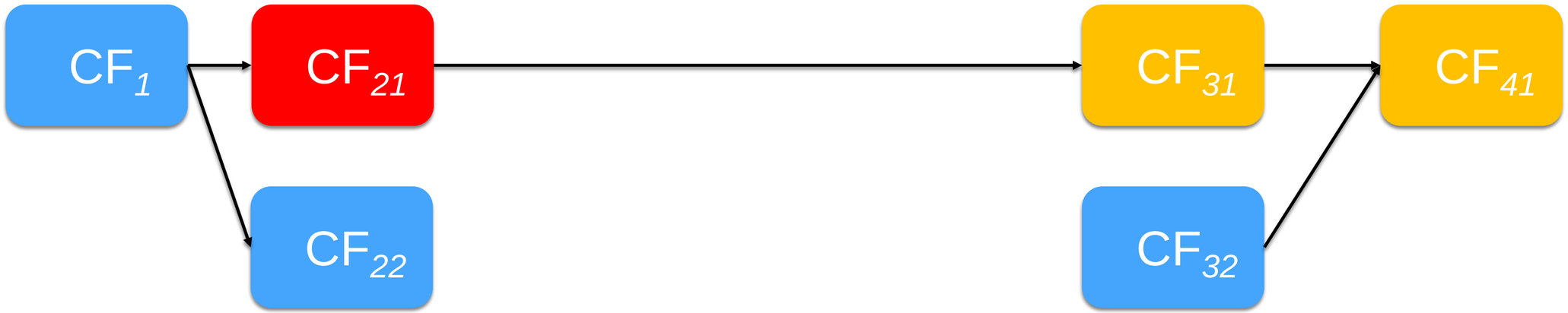
Suppose we have this CF pipeline



And CF_{21} raises an exception

Exception handling

Suppose we have this CF pipeline



And CF_{21} raises an exception

Then all the depending CF are in error

Exception handling

Which means that:

- the call to isCompletedExceptionnaly() returns true
- the call to get() throws an ExecutionException which cause is the root Exception

Exception handling

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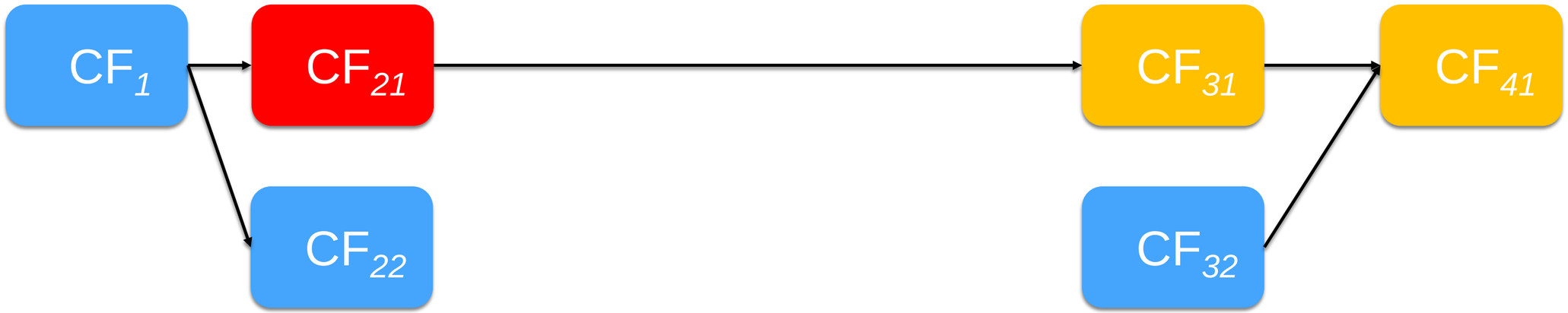
- the call to get() throws an ExecutionException which cause is the root Exception

CompletableFuture can handle exceptions

Exception handling

Suppose we have this CF pipeline

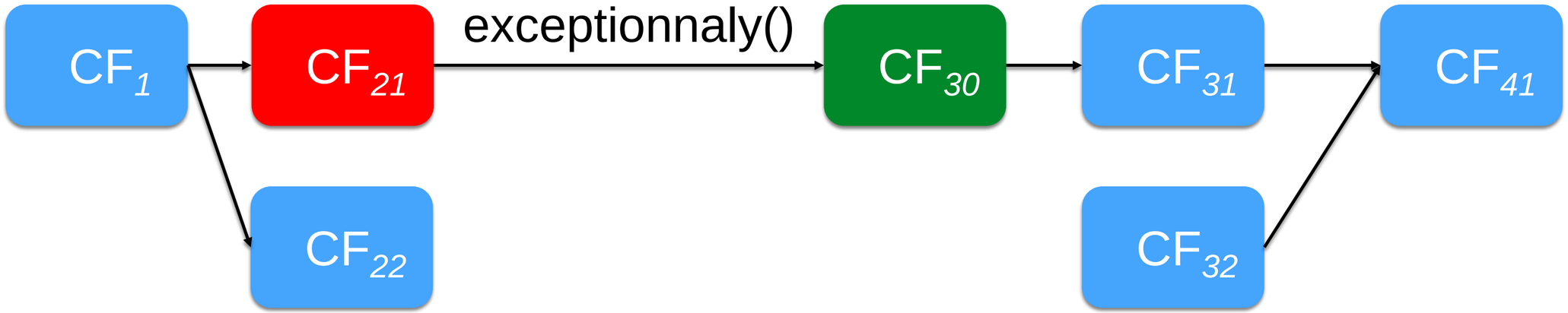


And CF_{21} raises an exception

Then all the depending CF are in error

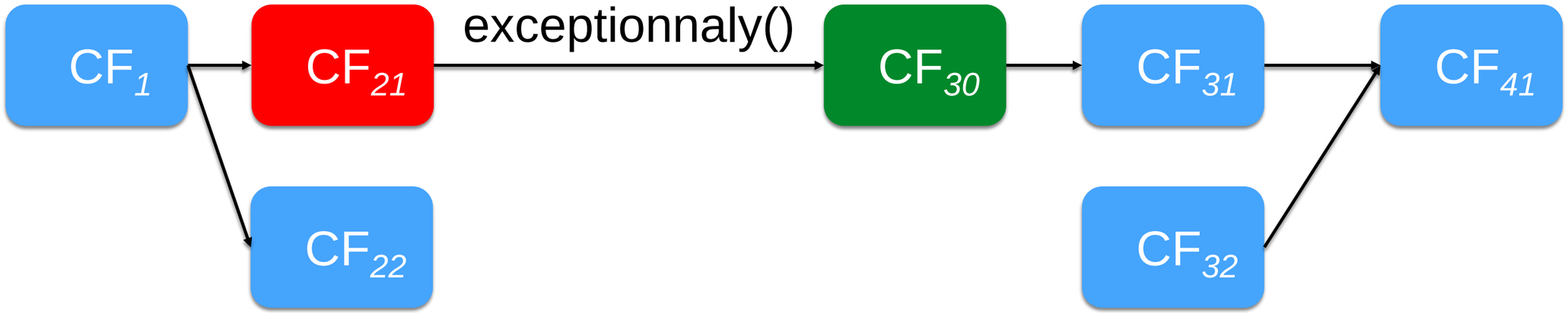
Exception handling

Suppose CF_{30} has been created with exceptionnaly()



Exception handling

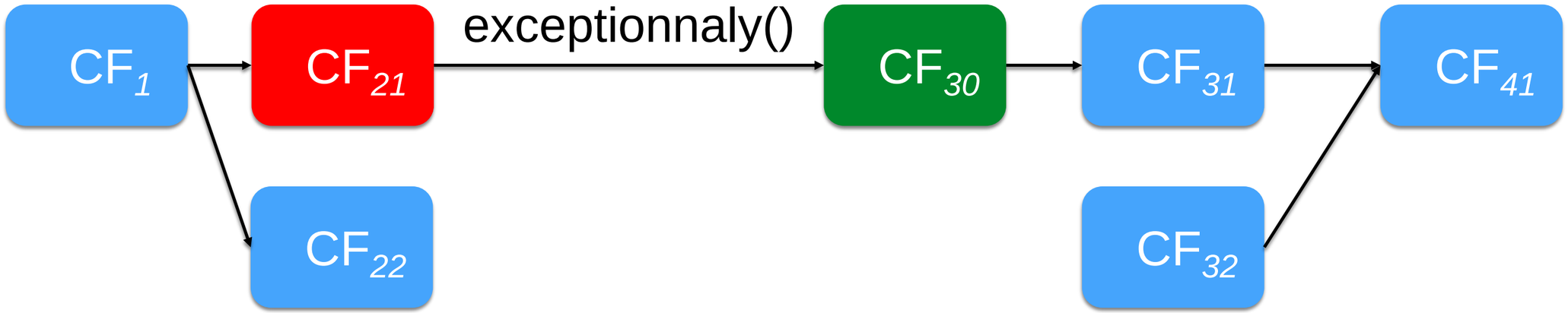
Suppose CF_{30} has been created with exceptionnaly()



If CF_{21} completes normally, then CF_{30} just transmits the value

Exception handling

Suppose CF_{30} has been created with exceptionnaly()



If CF_{21} completes normally, then CF_{30} just transmits the value
If it raises an exception, then CF_{30} handles it and generate a value for CF_{31}

Exception handling

There are three methods to handle an exception

```
CompletionStage<T> exceptionally(
    Function<Throwable, ? extends T> function);
```

Exception handling

There are three methods to handle an exception

```
CompletionStage<T> exceptionally(
   Function<Throwable, ? extends T> function);
```

```
<U> CompletionStage<U> handle(
   BiFunction<? super T, Throwable, ? extends U> bifunction);
```

handle() has also asynchronous versions

Exception handling

There are three methods to handle an exception

```
CompletionStage<T> exceptionally(
   Function<Throwable, ? extends T> function);
```

```
<U> CompletionStage<U> handle(
   BiFunction<? super T, Throwable, ? extends U> bifunction);
```

```
CompletionStage<T> whenComplete(
   BiConsumer<? super T, Throwable> action);
```

whenComplete() has also asynchronous versions

A very last example

```
CompletableFuture<String> closing = new CompletableFuture<String>() ;
Stream<String> manyStrings = Stream.of("one", "two", "three") ;
```

A very last example

```
CompletableFuture<String> closing = new CompletableFuture<String>() ;
Stream<String> manyStrings = Stream.of("one", "two", "three") ;



manyStrings
    .onClose(() -> { closing.complete(""); })
```

A very last example

```
CompletableFuture<String> closing = new CompletableFuture<String>() ;
Stream<String> manyStrings = Stream.of("one", "two", "three") ;



manyStrings
    .onClose(() -> { closing.complete(""); })
    .map(CompletableFuture::completedFuture)
```

A very last example

```
CompletableFuture<String> closing = new CompletableFuture<String>() ;
Stream<String> manyStrings = Stream.of("one", "two", "three") ;



manyStrings
    .onClose(() -> { closing.complete(""); })
    .map(CompletableFuture::completedFuture)
    .filter(cf -> cf.get().length() < 20)
```

A very last example

```
CompletableFuture<String> closing = new CompletableFuture<String>() ;
Stream<String> manyStrings = Stream.of("one", "two", "three") ;



manyStrings
    .onClose(() -> { closing.complete(""); })
    .map(CompletableFuture::completedFuture)
    .filter(cf -> cf.get().length() < 20)
    .reduce(
       closing,
       (cf1, cf2) -> cf1.thenCombine(cf2, binaryOperator) // concatenation
    );
```

A very last example

```
CompletableFuture<String> closing = new CompletableFuture<String>() ;
Stream<String> manyStrings = Stream.of("one", "two", "three") ;

CompletableFuture<String> reduce =
manyStrings
   .onClose(() -> { closing.complete(""); })
   .map(CompletableFuture::completedFuture)
   .filter(cf -> cf.get().length() < 20)
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       closing,
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    );
manyStrings.close();
```

A very last example

```
CompletableFuture<String> closing = new CompletableFuture<String>() ;
Stream<String> manyStrings = Stream.of("one", "two", "three") ;

CompletableFuture<String> reduce =
manyStrings
   .onClose(() -> { closing.complete(""); })
   .map(CompletableFuture::completedFuture)
   .filter(cf -> cf.get().length() < 20)
   .reduce(
      closing,
      (cf1, cf2) -> cf1.thenCombine(cf2, binaryOperator) // concatenation
   );
manyStrings.close();
```

A very last example

```
CompletableFuture<String> closing = new CompletableFuture<String>() ;
Stream<String> manyStrings = Stream.of("one", "two", "three") ;

CompletableFuture<String> reduce =
manyStrings.parallel()
    .onClose(() -> { closing.complete(""); })
    .map(CompletableFuture::completedFuture)
    .filter(cf -> cf.get().length() < 20)
    .reduce(
       closing,
       (cf1, cf2) -> cf1.thenCombine(cf2, binaryOperator) // concatenation
    );
manyStrings.close();
```

A very last example

```
CompletableFuture<String> closing = new CompletableFuture<String>() ;
Stream<String> manyStrings = Stream.of("one", "two", "three") ;

Runnable sillyStreamComputation = () -> {
  CompletableFuture<String> reduce =
   manyStrings.parallel()
      .onClose(() -> { closing.complete(""); })
      .map(CompletableFuture::completedFuture)
      .filter(cf -> cf.get().length() < 20)
      .reduce(
         closing,
         (cf1, cf2) -> cf1.thenCombine(cf2, binaryOperator)
      );
   manyStrings.close();
}
```

A very last example

```
CompletableFuture<String> closing = new CompletableFuture<String>() ;
Stream<String> manyStrings = Stream.of("one", "two", "three") ;

ForkJoinPool fj = new ForkJoinPool(4);

CompetableFuture<String> criticalParallelComputation =
   CompletableFuture.runAsync(sillyStreamComputation, fj);

someCriticalResult = criticalParallelComputation.get();
```

Conclusion

We have an API for async computations in the JDK!

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Very rich, many methods which makes it complex

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Handle chaining, composition

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Handle chaining, composition

Very clean way of handling exceptions


Thank you


Q/A